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EVERYDAY BOTANY

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PREFACE

THOUGH many aspects of modern life are affected by scientific progress, and botanical science can claim a fair share of credit for the beneficial part it plays in this advance, it is scarcely too much to say that, in the minds of most people, botany is not considered to be in the same sphere of usefulness as physics and chemistry. It is still commonly regarded as a study more appropriate for the gentler sex than for other people ; and its scope is often supposed to be purely academic, determined therefore by the syllabuses of examination authorities and embodying details which can be readily forgotten after the necessary credit has been obtained at school.

There is no doubt that botany, and, indeed, biology itself, is still badly neglected as an educational subject, especially in boys' schools. Without going far to seek the reasons, it may be said that one is because little attention is usually given to the *everyday* aspect, although it is for this very reason that authorities are now pleading for the inclusion of biology in all school courses. Few chemistry textbooks deal with chemical elements and compounds without also discussing their commercial manufacture and uses ; and a physics textbook—even an elementary one written especially for a definite grade of examination—is a veritable epitome of everyday life—heat, light, radio, telephony, and so forth. There is every reason, therefore, for botany to be treated in a similar way.

Such has been the aim of this book. Naturally, just as in the case of textbooks on chemistry and physics, the purely academic interest of the subject has not been made subservient to its everyday applications. A true appreciation of the applied side of science can only be attained on a basis of 'pure' science. The immediate aim has been to present botany as a progressive branch of science, with the ultimate aim of showing its utilitarian value.

The requirements of the student working for examinations have not been neglected, however, and the subject matter covers the syllabuses of the various School Certificate and Matriculation examinations. In this connexion, it may be stated that the physiological aspect has been emphasised in order, if possible, to treat the plant as a living entity. It is worthy of note that a large percentage of examination questions are physiological.

By dealing with the everyday applications of plants and their products, such as foodstuffs, commercial commodities, etc., it is hoped that the book will prove useful not only to students reading for School Certificate examinations, but also as a means of introducing the subject to those who hope finally to take up medicine, pharmacy, forestry, horticulture or agriculture as a career.

My thanks are due to Messrs. Macmillan and Co., Ltd., for the use of some illustrations from other of their publications, and also to various authorities for permission to reproduce certain diagrams and photographs. The sources of these will be found in the appropriate places. It is hoped that the inclusion of such authoritative illustrations will add to the value of the book. More than 130 other illustrations have been prepared by myself.

I also wish to express my thanks to Mr. N. P. Gough for much help in the preparation of the index.

From the earliest stages in the preparation of this book, I have been fortunate in having the generous help of my principal, Sir Richard Gregory, Bart., F.R.S. He proffered much valuable advice, and thus helped me to formulate the aims and scope of the book in the beginning. Throughout the writing of the text and the drawing of my diagrams his guidance and criticism were invaluable ; and I had the benefit of his help during the whole of the time that the book was going through the Press, in proof-reading, etc. If the book wins the approval of the reader, for which I am hoping, it will be due in no mean measure to Sir Richard Gregory, to whom I am grateful.

L. J. F. BRIMBLE.

LONDON, *June* 1934.

CONTENTS

CHAPTER I

LIVING THINGS

In the minds of many people the science of botany, or the study of plant life, signifies scarcely anything more than a subject of academic or cultural interest. The question is often asked, "What is the use of it ?" Of course, this question is constantly cropping up in connexion with all branches of science—"Yes, a most interesting discovery ; but what is the use of it ?"

It sometimes happens that a discovery has an immediate use, but more often the only answer to the question is that the discovery may prove useful some day, or that it may form a rung in the ladder to greater heights of achievement. In any case, every discovery, however academic or 'economically useless' it might seem superficially, must always be welcomed as an achievement, another impetus to the march of the times—Progress. For the world admires nothing more than something having been done—*achievement*—whether in sport, art, literature, politics, business, science, or in breaking speed records.

Who would have thought, for example, that Michael Faraday's discovery of electro-magnetic induction, in the Royal Institution in 1831, would have revolutionised transport, travel, lighting, heating, and all forms of industry and so forth—in the application of electricity to everyday life ? Certainly not the discoverer himself. Yet, when asked what was the use of it all, Faraday made the epigrammatic reply : "What is the use of a newly born baby ?"

So may the same be said of the science of botany. When it is known that botany involves much more than the mere counting of petals on a flower, and really includes *everything relating to the plant kingdom and its cultivation*, then it will be realised that many discoveries have been made and have developed

and produced important results, though in their early stages they seemed scarcely to justify their existence.

To-day, a knowledge of botany is essential in very many industries, occupations and vocations. A knowledge of the structure (**morphology**) of plants is necessary to all who are seriously interested in their cultivation—for example, farmers, gardeners, planters (tea, rubber, sugar, etc.); the function of plants and their life processes (**physiology**) to the same type of person and to the physician; the structure of fossil plants (**palæobotany**) to the geologist and others interested in the past and present structure of the earth; the diseases of plants (**plant pathology**) to all cultivators; and the breeding of plants (**genetics**) to all who are concerned with obtaining new or better types of fruits, flowers or vegetables.

It is, however, useless to try to run before learning to walk; therefore, before studying the practical uses of botany and how plants are related to the needs and interests of everyday life, it is desirable to examine the plant from the purely structural and functional points of view. Closely connected with such work are the classification of plants (**systematic botany**), their distribution (**geography**), and their relations to each other and their surroundings (**ecology**). After a general acquaintance with the nature of these fields of inquiry the romance of plant life will reveal itself, and it will be realised what an important science botany is and has been since man learned to make use of plants and their products for his pleasure and sustenance.

In the study of plants, whether they are in a condition of health or disease, it is necessary to remember that they are living things. It may seem easy to define what are living things, because the average living thing is so *obviously* alive, but actually to do so with scientific accuracy is really very difficult. All that can be said is that living things possess certain characters in common, and these provide the power which results in the phenomenon of what we call **life**.

On the other hand, other familiar objects, such as a piece of glass or a bar of iron, have no life and are said to be non-living. A dead plant or animal could conceivably be placed in the latter category. Actually, however, dead things are not classified with

non-living things ; for the latter has no life, but, more important still, it never did possess life. On the other hand, a dead thing, though it no longer possesses life, did so at one time. There are, therefore, three forms of matter from the botanist's point of view: **living, dead,** and **non-living.**

Differences between Living and Non-Living

It is easy, of course, to distinguish between a living and a dead thing. The former has life and the latter, though it did possess life at one time, has now lost it. It is, however, the non-living thing, rather than the dead thing, which concerns us most in the solution of the problem.

Men of science and philosophers, from very early times, have attempted to define life, and even to prove that *all* living things possess souls. **Aristotle,** the great philosopher, who may be looked upon as the 'father of biological research,' spent some considerable time trying to establish the presence of souls in plants. For many centuries it was not realised that to define life clearly is practically impossible. But the chief differences between living and non-living, to be considered now, were emphasised chiefly by **Professor Claude Bernard,** a great French man of science who lived in the nineteenth century.

Perhaps it is as well to realise from the beginning that we shall not completely reach our goal—that is, we shall not discover a fundamental difference between the living and the non-living. A *fundamental* difference, of course, is one which includes *every* case of living and non-living things on the earth.

However, disappointing though this problem may be, there is no reason why we should not attack it and see how far we can solve it. We are looking for a *fundamental difference between the living and the non-living.* Casual considerations bring several possibilities to the mind. For example, it may be suggested that living things move about, whereas non-living things do not. But a more detailed examination will reveal that this is not true of every case. No one would dream, for example, of suggesting that a railway engine, or an aeroplane, or a motor-car cannot move, yet they are undoubtedly non-living things.

Therefore, it must be agreed that mere ability to move is not a real distinction between these two great groups.

Take another example. It might be suggested that since we can see, therefore we are alive. The same could be said of the other senses. But this is not much help, for there are thousands of things, such as plants and many animals, which are living but possess no semblance of an eye and therefore cannot see. Also many unfortunate human beings are blind, yet are able to live quite well. So one could go on with other examples which, on their face value, give the fundamental difference we are seeking, but, on closer examination, are found to possess many exceptions.

Since, therefore, such a fundamental difference between the living and the non-living seems to be impossible to define, the next best thing is to try to find those differences which are the nearest to being complete. Actually there are three differences between the living and the non-living which will prove helpful to us, for although they do not embrace all cases, they do embrace the majority.

The first great difference between the living and the non-living is the power of **growth**. Nearly all living things grow during some part of their life, whereas the majority of non-living things do not. However, some do; for example, stalactites, which are formed in caves and under bridges by the deposition of calcium carbonate from constantly dripping water, gradually increase their bulk, chiefly in length; very slowly it is true, but it can be said that they are growing. Also, the crystals of some chemical substances, such as copper sulphate, will grow in size if placed in a solution of the same substance. Growth is therefore not an exclusive characteristic of life; but the exceptions are so few that it may be looked upon as being a good characteristic of living things.

The second difference is more distinct. It is well known that living things possess the power of producing new living things—that is, young ones like themselves. For example, birds lay eggs from which young birds are hatched; horses give birth to foals which finally grow up into adult horses; and many plants produce seeds from which new plants develop.

There are many ways in which living things produce new

living things, and the process is called **reproduction.** Not a single non-living thing can do this. So the power which living things possess of reproducing themselves seems to be an excellent distinction. But, it is not infallible, for there are exceptions. Many living things do not possess the power of reproduction.

The third difference is less perfect than either of the other two. If you were to put your finger on a red-hot poker, you would soon withdraw it. You feel the heat, and since it is painful you remove yourself from the source of the heat. On the other hand, if a non-living thing like a bar of iron were in your place it would not move away. Again, most plants, especially green plants, like light ; in fact, it is necessary to them. If such a plant were put in a darkened place, with just a little light coming from one point, it would slowly bend towards the source of light. In these two cases, it is said that the animal **responds** to the heat and the plant responds to the light (see Chap. XXII). The light and the heat are referred to as **stimuli** and the plant responds to the stimulus of light. This ability of living things to respond to stimuli gives us the third difference.

These three differences between the living and the non-living are the best that are known at present. They are:

(1) Living things possess the power of growth, whereas few non-living things do.
(2) Most living things possess the power of reproduction, whereas no non-living things possess such power.
(3) All living things possess the power of response to various stimuli, whereas few non-living things possess such power.

Plants and Animals

There are two great groups into which living things may be classed : **plants** and **animals.** Both the plant and animal kingdoms are much more extensive than we usually imagine, as will be shown in Chap. II.

Now, it has already been seen that a clear line of demarcation cannot be drawn between the living and the non-living. Similarly, it may be said that *Nature knows no hard and fast lines of distinction between plants and animals.* Therefore, in some cases, the question of grouping these living organisms is a difficult one. To

get over this difficulty, such cases are placed in neither of the great groups, but are given a group to themselves and are called **plant-animals.** But these plant-animals are comparatively rare; all of them are so small that they cannot be seen with the naked eye, so we can afford to ignore them in this present study.

There are millions of different plants; but there are even more millions of different kinds of animals. Plants vary in size and form, from the majestic trees of our forest and woods to specimens much smaller than grains of dust; for example, bacteria.

Many plants and animals are so small that they cannot be seen with the naked eye. In this respect, they resemble the stars in the heavens. On a clear night many stars of different sizes may be seen; but if an instrument called a **telescope,** which enables much fainter bodies to be seen, be used, then many more stars are revealed—stars which cannot be detected by the unaided eye. Only about five thousand stars are visible in the whole heavens to the naked eye, whereas at least a hundred millions can be seen through a large telescope.

In a somewhat similar way plants and animals may be examined. The instrument used for this purpose is called a **microscope.** It can magnify views of plants and animals many hundreds of times. If the microscope had never been invented (see Chap. V) many plants and animals, now familiar to the scientific worker, would have escaped his knowledge. Fig. 1, for example, is a drawing of a complete plant, magnified 1500 times. This plant thrives in fresh water and is called *Chlamydomonas*. It can be seen only with the aid of a microscope, and is clearly different in size and form from, say, an elm tree.

Differences between Plants and Animals

Just as it was found desirable to get some idea of what is meant by life, so is it necessary to consider what is meant by a plant and an animal. The best way to do this will be, as in the previous case, to differentiate between the two organisms, and since Nature knows no hard and fast rules and lines of differentiation, we shall find it impossible to do this with absolute precision. There is no fundamental difference between plants and animals. If there were, the organisms called plant-animals would not exist.

Consider some of the superficial differences. For example, it might be suggested that an animal such as a dog has a head, legs and tail, whereas a plant has not. The latter is true of all cases; but the former certainly is not, as in the case of a jelly-fish or an oyster. Again, it might be said that plants have roots, stems, leaves and flowers, but that animals have not; but there are thousands of plants which do not possess such things, as, for example, *Chlamydomonas* (Fig. 1). So we could go on in this fruitless effort to find an *absolute* distinction between plants and animals—that is, one which involves all known cases. Nevertheless, as in the previous problem, this does not deter us from looking for certain differences which involve the majority of cases.

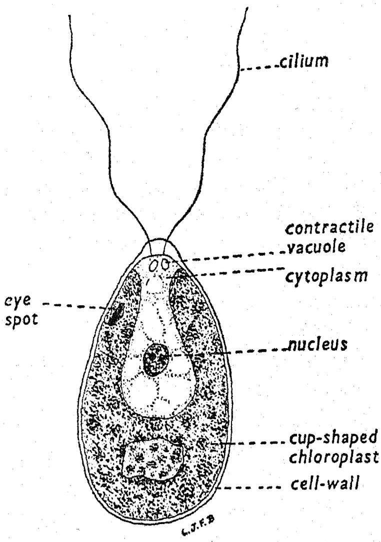


FIG. 1. *Chlamydomonas*, A UNICELLULAR PLANT (× 1500).

There are three such distinctions, one of which is of primary importance. The other two are only secondary, for there are so many exceptions to them. These can therefore be dismissed in a few words.

First, the majority of animals are free to move about, whereas the majority of plants are stationary. The reason for this is that plants can obtain their food without moving; but animals have to go in search of it. Yet there are many exceptions. Coral, for example, is stationary during the greater part of its existence, and, on the other hand, *Chlamydomonas*, a plant, can swim freely in the water.

Plants, in contradistinction to animals, are usually branched. This is clearly seen in the case of our familiar trees, shrubs and herbs; but there are many exceptions in other plants, such as

Chlamydomonas and bacteria. Few animals are branched; in fact, most animals are of a definite shape. This gives us another good distinction between the two groups.

The third difference between plants and animals, although not a perfect one, is by far the best and is of the greatest importance to all living things. The difference lies in the way in which plants and animals obtain their food.

Nutrition

All living things must have food in order to carry out the manifold processes necessary to their existence. Plants and animals absorb food-stuffs into their bodies. We, for example, take food either as a solid or a liquid, through the mouth, whence it passes to the stomach, and thence into other parts of the gut. During this passage from the mouth and through the gut, the food is **digested** (see Chap. XI). The whole process of taking in food, whether it be in plants and animals, and absorbing it into the system of the organism, is called **nutrition.**

All food-stuffs are chemical compounds, some rather simple ones, such as water, and others very complex, such as those found in meat. The chief elements which unite in different ways to give the hundreds of different compounds in foods are: carbon, oxygen, hydrogen, and nitrogen. Other elements are found in some foods, such as sulphur and phosphorus. The question is: how do these elements unite to produce the various food-stuffs known to us?

The elements are comparatively easy to obtain, since they are present in the soil and the air. Once extracted from these sources they are built up by various complex chemical processes into the different forms of food. The manner in which the elements unite gives the clue to the difference between plants and animals.

It is well known that chemical elements will unite to form chemical compounds. Sometimes they unite spontaneously; but often the reaction has to be stimulated by heat or the presence of another chemical. Such cases will be considered later. The chemical compounds present in food-stuffs are not formed by the spontaneous union of the elements. The elements will not

unite except in the presence of the green colouring matter which is so characteristic of green leaves and young stems. This colouring matter is a mixture of several chemicals (see Chap. XI) and is called **chlorophyll.** *In no circumstances are foods manufactured in Nature from the raw elements without the help of chlorophyll.* Therefore *the essential regions of food manufacture are foliage leaves.* They may be looked upon as the food factories of the plant.

Thus, by virtue of possessing green leaves containing chlorophyll, plants can manufacture their food-stuffs from the raw elements. On the other hand, animals cannot, for they do not possess chlorophyll. Yet animal food is essentially similar to plant food. Since, therefore, animals cannot manufacture food for themselves, they must perforce depend upon plants for it. That is the reason why we ourselves eat such plant organs as potatoes, cabbage, peas, nuts, fruit, etc. We cannot manufacture our food, so we consume those living things which do. Some animals depend directly upon plants for their food ; for example, the rabbit, which in the wild state lives entirely on the vegetation around it. On the other hand, some animals eat very little plant food ; for example, the dog, lion and many snakes. They eat other animals and animal products, such as bone, meat and milk. But, such animals still ultimately depend upon plants for this food. For example, a cat can live almost entirely on milk, but the milk comes from the cow and the food present in the milk has been produced by the cow from the grass and other plants which it had formerly eaten. Thus there are two types of animals from the point of view of nutrition : those which depend upon plants directly, like the rabbit ; and those which depend upon plants indirectly, like the dog. There is a third type such as ourselves, which depend upon plants directly by consuming plants, and indirectly by consuming other animals.

In one way, therefore, plants are much more independent living things than animals. They could live on the earth quite comfortably if animals were non-existent ; but, without plants, the whole animal kingdom would soon perish. Here lies the chief point of difference between the two groups. It is a difference of nutrition. Plants manufacture their own foods ; animals take

theirs already manufactured. The former is called **holophytic** nutrition and the latter **holozoic.**

This distinction in mode of nutrition is not a fundamental one, for there are many exceptions. Some plants, such as the mushroom, are not green and therefore contain no chlorophyll. They therefore are not holophytic (see Chap. XIV). Also a few animals are holophytic. Such animals are all microscopic; but they contain chlorophyll.

The chief differences between plants and animals therefore are:

(1) Many animals move about; few plants do.
(2) Many plants are branched; few animals are.
(3) The nutrition of plants is holophytic; and that of animals is holozoic.

The study of all living things is called **biology**—that is, the study of life. It is possible, of course, to study life from many points of view, and therefore the science of biology may be subdivided. For example, the study of animals is called **zoology**, from the Greek, *zoön*, animal, and *logia*, to speak: and the study of plants is called **botany**, from the Greek, *botanē*, herb. We shall concern ourselves chiefly with the study of botany, with an occasional reference to zoology in an attempt to get a clearer idea of the kingdom of plants, its constitution and how it works.

CHAPTER II

THE PLANT KINGDOM

It is quite clear, merely from a casual observation of the vegetation of a garden or a meadow, that plants vary, to a considerable degree, in size and form. A clear idea of the nature of plant life cannot, therefore, be obtained from a study of plants in general. It is necessary to secure first of all some conception of the various types of plants and then to examine a few in greater detail.

Now, though it is obvious that many plants differ from each other, it is just as clear that others resemble each other very closely. In this respect the plant kingdom may be said to resemble a whole nation of people. A casual study of any crowd of people will show that although the individuals are different from each other, yet, in many cases, there is a strong resemblance. For example, we might meet two negroes in the street. They resemble the white man very closely in that they have the same organs such as legs, arms, eyes, and they can talk and think like the white man. But they differ in that their skin is very dark in colour, their facial features are of a different shape, etc. Thus they can be separated from the white man because they differ from him ; but both white and black can be classed together because in spite of minor differences they do resemble each other.

In this way could we go on subdividing people into various grades or classes, just like the classes or forms in school. Such a segregation into classes is referred to as **classification.**

Plants too are classified in a similar manner. Attempts to classify plants have been made from the earliest times. Aristotle and his pupil, **Theophrastus,** did so ; and many have done so since. A brief survey of the present-day methods used in classification must be left for later consideration (see Chap. XXIV).

Many plants bear seeds ; on the other hand, many other plants

do not. The total number of different kinds of seed-bearing plants, alone, on the earth is approximately 120,000.

Plants, therefore, may be classified first into two great groups: those which bear seeds and those which do not. This classification, however, like all classifications, cannot be absolutely rigid, for Nature knows no sharp lines of demarcation.

Seed Plants and Non-Seed Plants

The classification of plants into **seed plants** and **non-seed plants** is essentially a broad one. Still bearing in mind these two

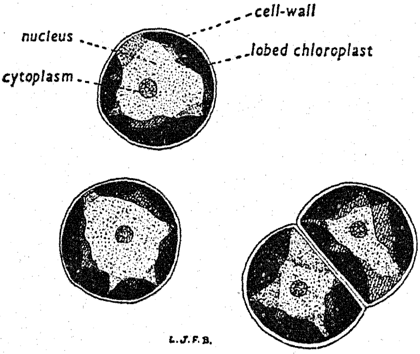


FIG. 2. *Protococcus*, A THALLOPHYTE ($\times 840$).

great groups, the plant kingdom can be subclassified into five divisions, three of which contain non-seed plants, and two, seed plants. The five divisions can be arranged roughly in order of complexity—that is, from simple to complex.

(1) **Thallophyta.** The simplest kinds of plants, which, however, are not necessarily the smallest, are found growing chiefly in the sea, lakes, rivers, ponds, and also on land in very damp situations. They constitute the group Thallophyta. An example of this group is *Chlamydomonas* (Fig. 1). Another is the green, powdery growth seen on damp wood and the bark of trees. This green powder is actually composed of millions of the small, microscopic plant called *Protococcus*. This plant is roughly spherical in shape as seen in Fig. 2, and is clearly a real plant, for it is green and therefore holophytic. *Protococcus* will not live

unless it is present in damp situations where plenty of water is available. This is well illustrated by the way in which it grows on the trunks of living trees. The windward side of the trunk is

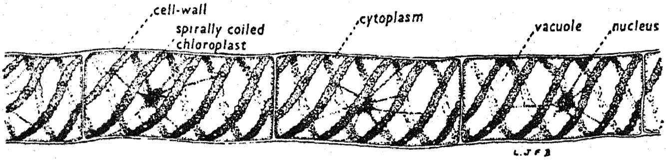


FIG. 3. *Spirogyra*, A THALLOPHYTE (×110).

usually much damper than the leeward side, since the rain beats with the wind. Hence the windward side appears much greener owing to the presence of many more millions of these *Protococcus* plants, especially after a storm of rain.

Another plant, simple in structure, and belonging to the same group, is the one responsible, together with other plants, for the green scum seen floating on the surface of stagnant ponds and pools. If a little of this scum is taken and placed in a glass of water, it will be seen to be composed of threads or filaments. These green filaments are plants called *Spirogyra*. Under the microscope this plant presents a very beautiful appearance (see Fig. 3).

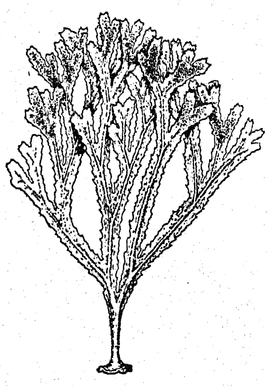


FIG. 4. THE SEA WRACK (*Fucus serratus*), A THALLOPHYTE ($\frac{1}{16}$ natural size). (*After Thompson.*)

Next we come to those plants which, though comparatively simple in structure, are much more complicated than those so far considered in this group. They are the seaweeds, which, as their name implies, grow in the sea. Some seaweeds are very familiar. Fig. 4 shows a well-known seaweed called the sea wrack (*Fucus serratus*). It appears to be formed of stems and leaves; but actually it is not, for although those structures are different in shape, their internal structure is very similar, whereas the internal structures of true stems and

leaves differ considerably. The stem-like portion of the seaweed is called the **stipe**, and the leaf-like portion, the **thallus**. The bladders which are found on some species of seaweed are to make the thallus buoyant so that it sways about in the water and does not lie recumbent on the sea floor. At the base of the stipe is a flattened portion called the **holdfast**, by means of which the plant clings tenaciously to rocks, the piles of a pier, or the walls of a jetty (Fig. 5).

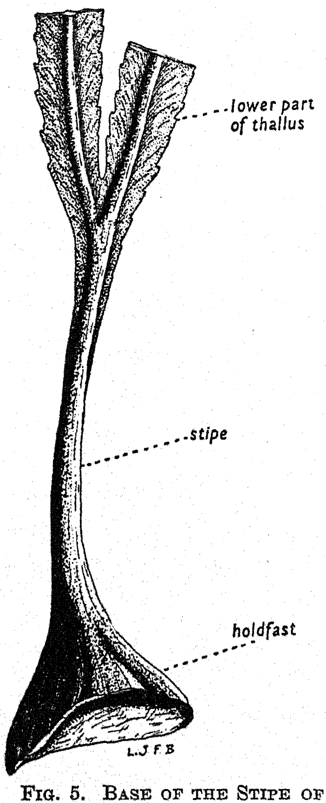


Fig. 5. Base of the Stipe of *Fucus serratus*, showing the Holdfast ($\times \frac{1}{2}$).

There are three groups of seaweeds, the **green**, the **brown**, and the **red**. The green seaweeds are found in very shallow water and are very often exposed to the atmosphere. The brown seaweeds either grow right under the water, or between tide marks, so that they become exposed at low tide. The red seaweeds are the less common of the three and grow in still deeper water.

Some seaweeds are very large. The thallus, in some cases, reaches a length of more than a quarter of a mile. What is called the Sargasso Sea, in the North Atlantic Ocean, is the centre of a vast eddy in which such seaweeds accumulate. Here they float on, and near, the surface of the water, and were at one time a great nuisance to navigation. This Sargasso Sea was first reported by Columbus, whose ship was involved in it for several days.

One would think that the brown and the red seaweeds, since

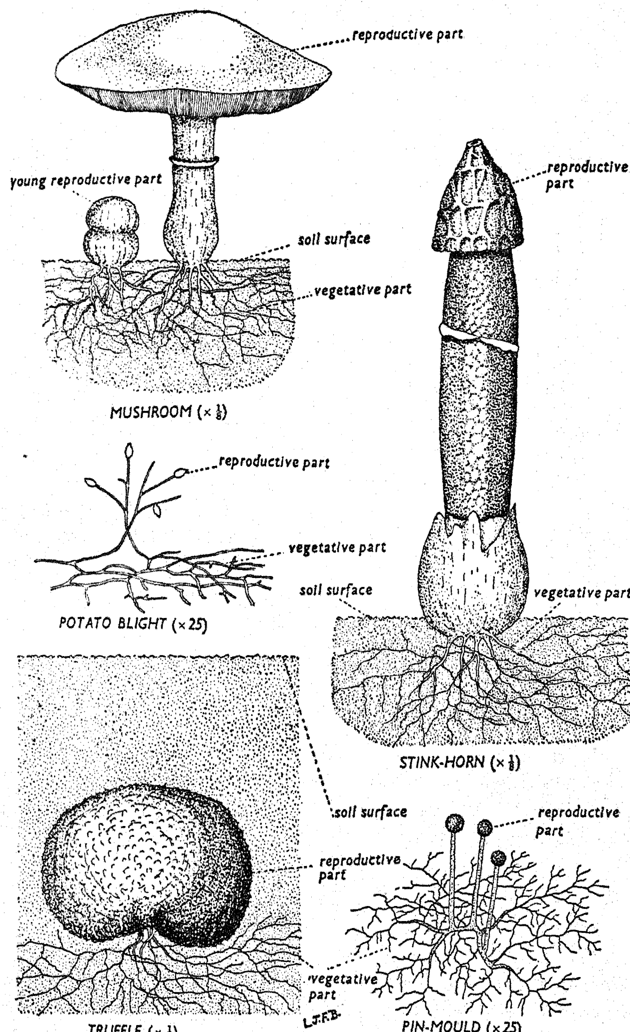


FIG. 6. TYPES OF FUNGI.

they are not green, could not be holophytic ; but actually they are, for they do contain chlorophyll. Brown seaweeds contain chlorophyll together with a brown pigment, which masks the green colour. Red seaweeds contain chlorophyll together with a red pigment.

All the plants so far considered are placed in the sub-group of the Thallophyta called **Algæ**. The other sub-group of the Thallophyta is the **Fungi**. This group contains a great variety of plants. Many of them are of microscopic dimensions, whereas others are comparatively large and conspicuous (Fig. 6). Some fungi are useful to man ; for example, the common edible mushroom (Fig. 6) and the truffle, a fungus which is an article of diet on the Continent but does not grow in Great Britain and is therefore expensive. A curious feature of this plant is that the edible portion, like the rest of the plant, grows below the surface of the soil (Fig. 6). It is therefore a difficult problem to locate the plant; and to dig up all the soil where its presence is suspected would be laborious and expensive. However, the farmers who cultivate truffles have discovered that pigs can smell the plants while they are still growing under the soil. The pig is therefore driven slowly over the ground and, since it is fond of truffles, it roots them up with its snout ; they are then immediately taken from the pig. Many fungi are very poisonous, such as the toadstools or ' seats of death'.

Other familiar fungi are the moulds which grow on decaying plant and animal material such as damp bread, jam, old leather and farmyard manure (Fig. 6). Other fungi, closely related to the moulds, live on other living plants and animals, thus causing disease, such as the potato blight disease (Fig. 6), various leaf-curl diseases, and the ringworm disease of human beings (see Chap. XIV).

Closely related to the fungi is a great group of plants called **Bacteria.** All the bacteria are of microscopic size. They may be spherical, rod-shaped or spiral (Fig. 7). They are of outstanding importance. Some are beneficial to man and the lower animals, others are useless but harmless, whereas others are very harmful. To get some idea of the size of bacteria, the number of times that the diagram is enlarged should be carefully noted.

(2) **Bryophyta.** The Bryophyta form the second group of the non-seed-bearing plants. This group contains all the mosses, **Musci**, and the liverworts, **Hepaticæ**, which are much more complicated in structure than the Thallophyta (Figs. 8 and 9). The majority of liverworts grow in damp situations or actually in fresh water. The plant body is called a thallus and is very similar in appearance to a green seaweed. Mosses, on the other hand, have a simple stem and leaf structure.

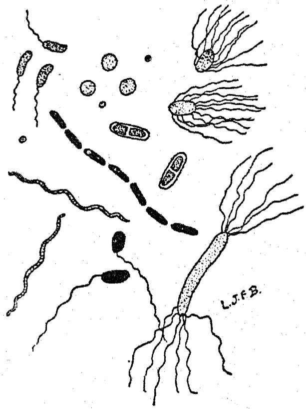


FIG. 7. TYPES OF BACTERIA ($\times 1500$).

(3) **Pteridophyta.** Still more complicated in structure than the Bryophyta are the Pteridophyta, which constitute the third group of non-seed plants. This group contains plants with a definite stem and root structure and a great variety of leaf forms. Such plants are very like the flowering plants with which we are so familiar, but differ from them in that they do not in any circumstances bear flowers. All the ferns belong to this group.

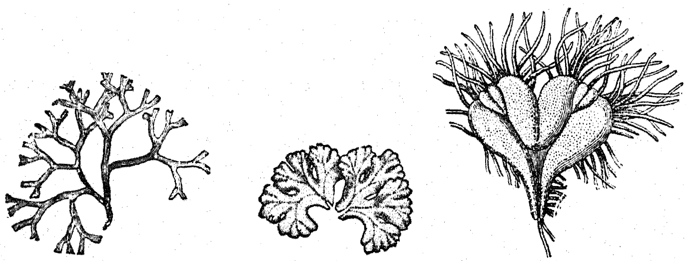


FIG. 8. TYPES OF LIVERWORTS ($\times 2$).

Well-known examples are the common bracken, which grows on heaths and in open woods, the shield fern (Fig. 10), which grows in damp, shaded places such as the banks of secluded streams, and the hart's tongue fern, which grows on dry banks and on

walls (Fig. 11). In tropical countries, especially in the forests, ferns attain a great size, even to the extent of being tree-like (Fig. 12).

(4) **Gymnosperms.** The Gymnosperms are the first group of the seed plants. Nearly all of them are trees. They bear flowers and seeds; but, unlike the next group of flowering plants such as the rose, dandelion, and pea, *the seeds are borne naked* and

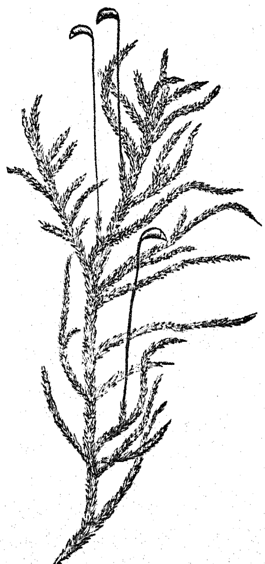


FIG. 9. *Scleropodium purum*, A MOSS (NATURAL SIZE).

FIG. 10. THE SHIELD FERN (*Nephrodium Filix-mass*).

A leaf ($\frac{1}{20}$) and, to the left, a portion of the under surface of the leaf bearing reproductive structures ($\times 2$).

(*After Luerssen.*)

exposed instead of being enclosed in a case. For this reason they are placed in a separate group. Well-known examples of the Gymnosperms are the pine, fir and larch trees (Fig. 13). They are nearly all large plants and, indeed, the group contains the largest and oldest examples of plants that exist to-day.

For example, the redwood (*Sequoia*) or big tree of California is so huge that in one case a carriage drive has been cut through the trunk, without killing the tree (Fig. 14). One of the largest of these redwood trees is still growing on the south side of San

Francisco Bay. It must be of very great age, although the exact date of its birth is not known. Its history was traced in 1931, and it was found that its earliest records go back to the first Spanish explorers of that region. In 1769 Gaspar de Pabola camped beneath it, and in 1777 it was already a very large tree

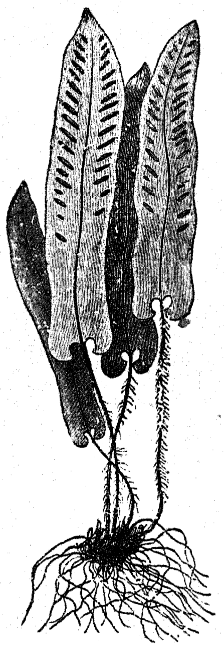


FIG. 11. THE HART'S TONGUE FERN (*Scolopendrium vulgare*) ($\frac{1}{4}$).

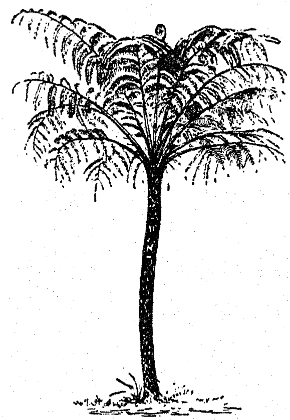


FIG. 12. *Alsophilla crinata*, A TREE FERN NATIVE TO CEYLON (VERY MUCH REDUCED).

with a height of 137·5 feet and a trunk with a circumference of 15 feet. Now the circumference is 23 feet. How this history could have been traced will be seen in Chap. III.

Gymnosperms used to be much more common on the earth than they are now, as fossil evidence shows.

(5) **Angiosperms.** The fifth and final group contains the most popular and well known of all the plants. They are the flowering plants which bear *seeds enclosed in some kind of case* (see Chap. XVIII).

We have now divided the plant kingdom into five groups, namely: Thallophyta, Bryophyta, Pteridophyta, Gymnosperms,

and Angiosperms. An interesting thing to note in connexion with this classification is that, apart from the Fungi, which, as will be seen, form a very exceptional group, all the Thallophyta

FIG. 13. LARCH TREES (*Larix europæa*) IN WINTER.
(*Photo. Henry Irving.*)

live either entirely submerged in fresh or salt water or in very damp situations. The Bryophyta and the Pteridophyta live chiefly in very damp situations or entirely submerged. On the other hand, nearly all the Gymnosperms and Angiosperms live on dry land.

There seems thus to be a gradual transition from simple to complex plants, and also from water to dry land. In this respect plants are similar to animals. There is reason for believing that

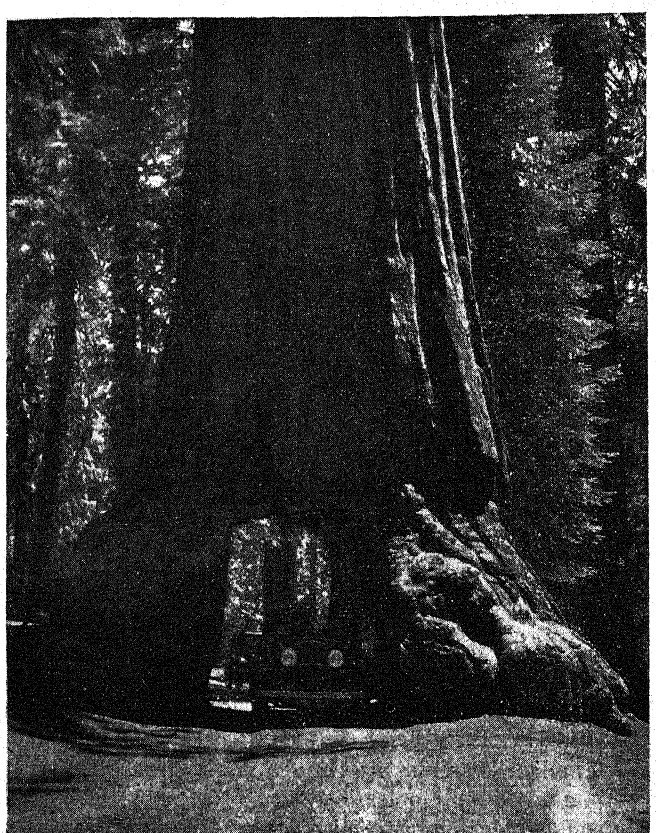


FIG. 14. A ROADWAY CUT THROUGH THE BASE OF A BIG TREE (*Sequoia*) AT WAWONA, CALIFORNIA.
(*Photo. Dr. Clyde Fisher, American Museum of Natural History.*)

all types of life in the first place began in the sea, and throughout the ages which stretch over millions of years, as the various organisms became more complex, they invaded the

land. To-day we have all stages of this process both in the plant and the animal kingdoms.

Plants and animals living in the sea (**aquatic**) and those living on the land (**terrestrial**) are very familiar; but we ought to be able to find some examples of those which have got more or less half-way between sea and land. Animals of this type—that is, which live part of their time in water and part of their time on dry land—are very familiar. The frog is an example. During its tadpole stages it lives in water and breathes by means of gills, like a fish. Then it gradually changes or **metamorphoses** into the frog stage, after which it lives chiefly on the land and breathes like us, with lungs. Such an animal is called an **amphibian**. In the plant kingdom, too, there are amphibians. The Bryophyta and Pteridophyta at one time in their life-history must have liquid water available and at another, dry conditions, especially during the process of reproduction. They may therefore be said to be amphibious.

Types of Flowering Plants

The average flowering plant is composed of roots, stems, leaves and flowers; but it is very clear that these structures vary considerably in dimensions, shape, colour and so forth. These different shapes are often so obvious and familiar that a cursory glance is sufficient to identify the plant. Nevertheless, in spite of these differences, many plants possess certain features in common and for that reason they can be divided into groups, according to their vegetative structure.

Some plants grow to a great size. The stem becomes thick and woody and is called a **trunk** or **bole**. These plants are called **trees**. Familiar examples are the elm, horse-chestnut (Fig. 15), hornbeam, beech and poplar.

A much greater number of plants vary considerably in height from a few inches to several feet—for example, violets, primroses, grasses, foxgloves and the sunflower. Although they all contain a certain amount of wood, this varies considerably, though it never amounts to as much as is present in a tree. For example, the dandelion stalk contains very little wood and is therefore much softer and juicier than the sunflower stem, which contains a much

greater amount of wood. All these plants are called **herbs** (Fig. 16).

Intermediate between the trees and the herbs are the **shrubs.** They are bushy plants with many branches and are all very

FIG. 15. HORSE-CHESTNUT TREE (*Aesculus hippocastanum*) IN WINTER.
(*Photo. Henry Irving.*)

woody. Unlike the trees, they do not possess a trunk—that is, the main stem is not so pronounced. Examples of shrubs are the privet, bramble, box and gorse (Fig. 17).

Length of Life

As a general rule, herbs carry out the whole of their life-history in one season. That is, they are born, develop, and reproduce themselves, all within the space of a year. Such plants are therefore called **annuals**. Wheat, barley, and the tulip are examples of annuals.

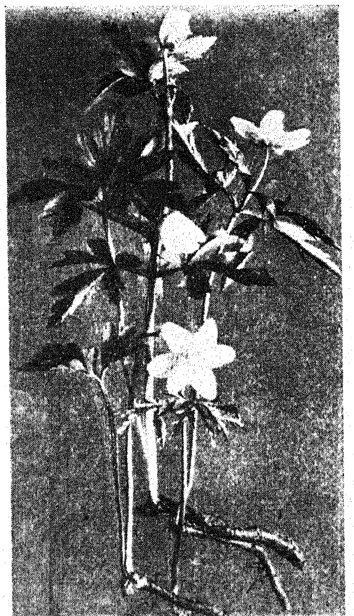


FIG. 16. WOOD ANEMONE (*Anemone nemorosa*), A TYPICAL HERB. (*Photo. Henry Irving.*)

FIG. 17. DWARF GORSE (*Ulex*), A TYPICAL SHRUB. (*Photo. Henry Irving.*)

Some plants can complete their life-history so quickly that the offspring which they produce can also complete their life-history in the same season. Thus we have two generations in one season. We might even get three or four generations. Such plants are called **ephemerals**, because their life is so ephemeral or short-lived. The groundsel is an ephemeral, and its quick growth makes it an objectionable weed in the garden. It should always be rooted out of the garden before it bears its

flowers, thus preventing at least one other generation of seeds from developing.

Some plants take two years to complete their life-history—for example, the foxglove and the beet. They develop vegetatively in the first year and produce seeds in the second, and are therefore called **biennials.**

Many plants go on living year after year, sometimes producing seeds every season and sometimes only once in several seasons. The majority of our trees and shrubs are of this nature and are called **perennials.** In some cases, such plants have been known to live for many years. Even in Great Britain there are some trees that are claimed to be thousands of years old. The biggest, and possibly the oldest, tree in the world is the cypress called the Big Tree of Tule, still growing in Mexico (Fig. 18). Its trunk is 50 feet in diameter where it begins branching. It is estimated as being 6000 to 7000 years old. Thus, it was a big tree when the ancient pyramids of Egypt were being built. The oldest tree in Scotland is a yew tree called the Fortingall Yew in Glen Lyon, Perthshire. It has an estimated age of more than 2500 years. It was therefore quite a large tree when Christ was born, and when the Romans invaded Britain. The Fortingall Yew in Perthshire and the Brabourne Yew in Kent are considered to be the veterans of European vegetation.

Nearly all arctic and alpine plants are perennials, because one season is far too short for them to complete a life-history.

Evergreen and Deciduous Plants

Perennials seldom maintain the same appearance throughout the year. The majority of British trees, for example, shed their leaves in the autumn and develop new ones in the spring. For this reason they are said to be **deciduous.** Those trees and shrubs which do not shed their leaves for the winter months are said to be **evergreen.** Holly, laurel and many tropical plants are of this nature. But it must be realised that although an evergreen bears leaves all the year round, it *does* shed its leaves. It does so continuously, but never all at one time.

Leaf-fall is clearly related to seasonal climate. The leaves of deciduous trees are shed just before winter sets in and that is

why plants growing in the low-lying, humid tropics, where there is little seasonal variation in climate, are nearly all evergreen.

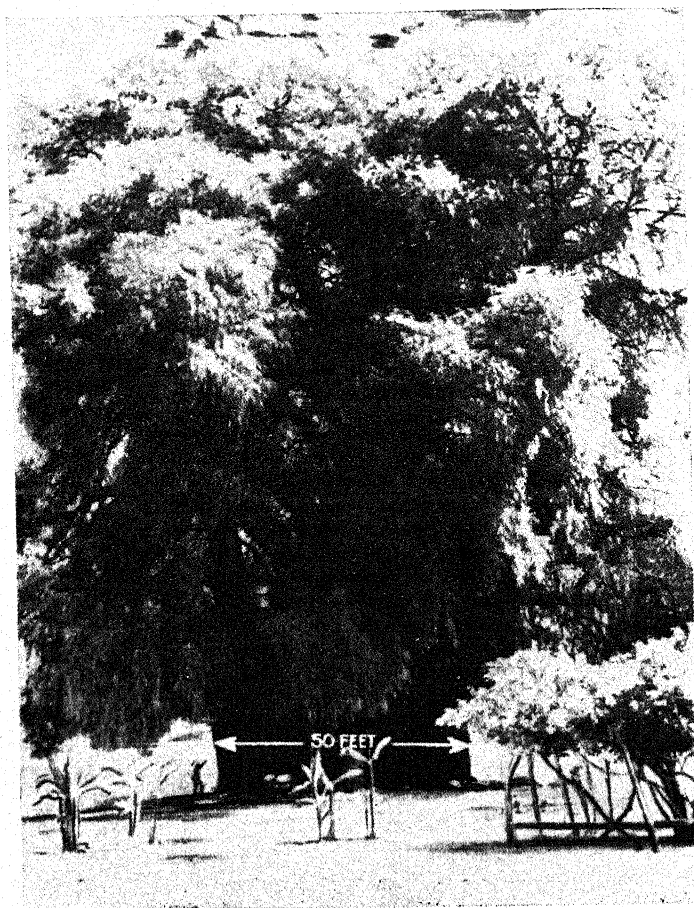


FIG. 18. THE BIG TREE OF TULE.
(Photo. Prof. C. J. Chamberlain, 'Scientific Monthly.')

Some plants may be said to be partially evergreen—that is, although they are never leafless like the true deciduous plants,

they have more leaves in the warm season than in the cold. Privet is an example of this. During the summer this plant is so thick with leaves that it is difficult to see through a hedge formed of it ; whereas, although the same hedge has some leaves in the winter, the number of leaves has become so much reduced that it is possible to see through it.

PRACTICAL WORK

Collect, draw and describe typical examples of the plant kingdom. In the case of large plants, such as shrubs and trees, it is useful to take photographs, provided a written description is given at the same time.

There are many common types of each plant group ; suggestions with regard to examples can be found in the text.

CHAPTER III

THE FLOWERING PLANT

A TYPICAL flowering plant, such as a buttercup, wallflower or elm tree, is clearly composed of various parts or **organs.** An organ is a part of a plant or an animal which is distinguished clearly by its shape and has certain definite functions to perform.

The organs of the flowering plant may be divided into two groups, namely that which normally grows below the soil, called the **root,** and that which grows above the soil, called the **shoot** (Fig. 19). Flowering plants, while conforming to general rules of structure, diverge from such rules in many ways. Such differences are called **modifications** (see Chap. IV).

The Root

The root performs several functions, the two chief of which are to anchor the plant firmly in the soil and to absorb water and substances dissolved in it from the soil, for the use of the plant. Many plants store food, and the stores are kept in various parts of the plant. The root is the store-house in some cases, such as the carrot and beet.

If a wallflower plant be dug up from the soil and thoroughly washed, it will be seen that the root system is composed of a main root or **tap** root, which grows vertically downwards. This gives off branch or lateral roots, which grow out obliquely from the tap root, and these branch roots are further branched. Near the tips of all the roots may be seen a tuft of very fine white hairs called **root hairs.** The main or tap root is the first which grows out from the seed. The branches appear later (Figs. 20 and 21).

Differing from the tap root system is that system of roots, equally as common, where the first root, instead of persisting

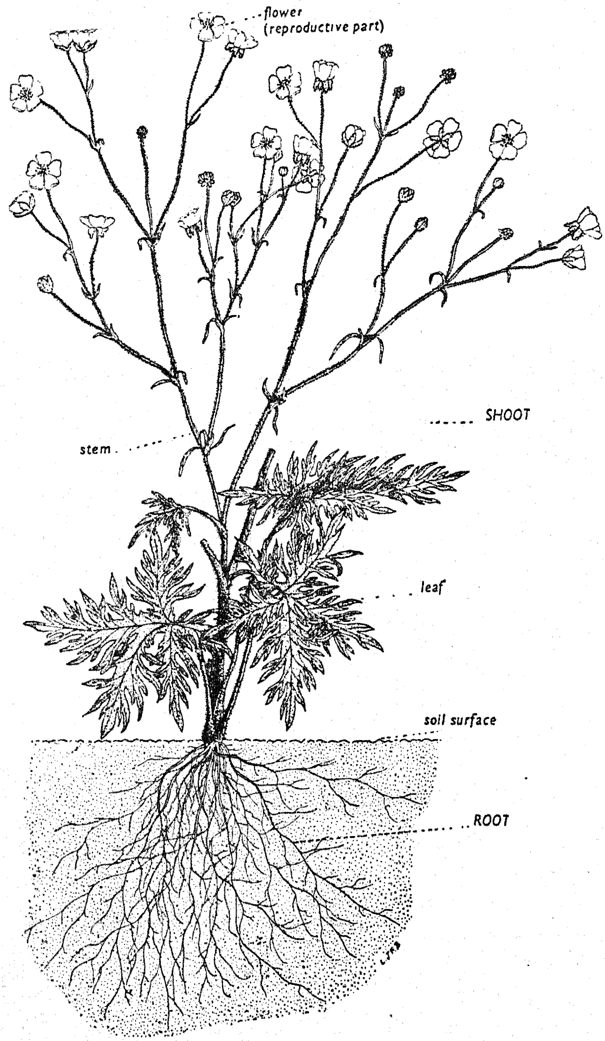


FIG. 19. A BUTTERCUP PLANT.
For clarity, some of the stems and leaves have been omitted.

and remaining the main root, withers away and a series of roots, more or less equal in size, takes its place. This can be seen in the case of grasses and is called a **fibrous root** system (Fig. 22).

The majority of the roots of the fibrous root system are given off from the stem, and are therefore not produced by the first root. A root which grows from any part of a plant other than the first, original root is said to be **adventitious**, and therefore most fibrous root systems are adventitious. Such adventitious roots will be seen to be given off from the stem chiefly (Fig. 22), and sometimes from leaves. Cut ends of stems of the geranium, carnation, *Verbena*, *Fuchsia* and willow, when placed in water or the soil, often give off such adventitious roots. Willow branches are often used for fencing on farms, and it is quite common to see such props giving off shoots, because they have 'taken root', by means of adventitious roots, in the soil. In the water-cress (*Nasturtium officinale*), adventitious roots are frequently borne on the stem, especially near the leaf axils (Fig. 23).

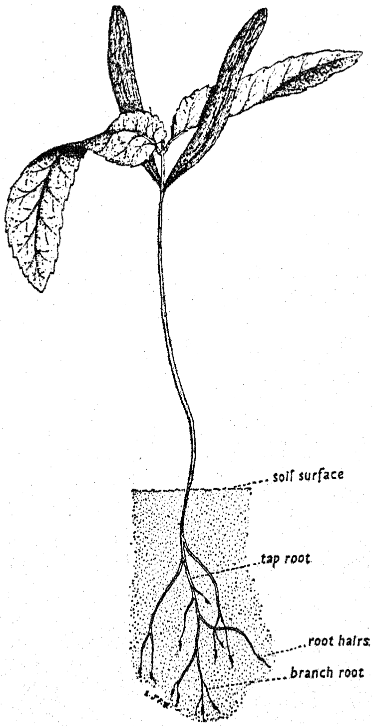


FIG. 20. A YOUNG SYCAMORE PLANT, SHOWING A TAP ROOT SYSTEM.

The Shoot

The shoot is composed of stems which bear leaves and flowers. In the case of the buttercup or wallflower, the shoot is composed of a central axis or main stem which terminates in a bud.

Wherever this **terminal** bud is a leaf bud only, it is capable of opening out and continuing the growth in length of the main

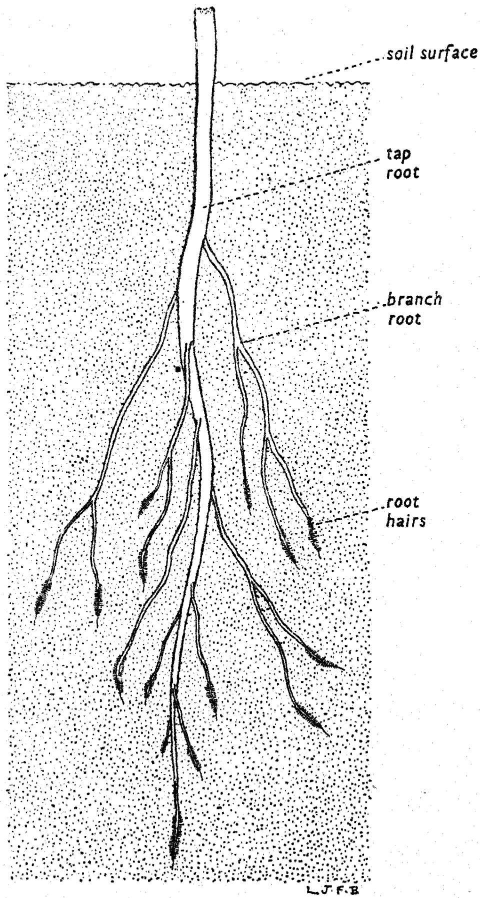


FIG. 21. A TYPICAL YOUNG TAP ROOT SYSTEM.

stem. If, however, the terminal bud contains a flower, once it has opened and flowered growth in length *in that direction* ceases.

Buds

On the side of the stem the leaves are borne (Fig. 19). That part of the stem to which a leaf is attached is called a **node.** The

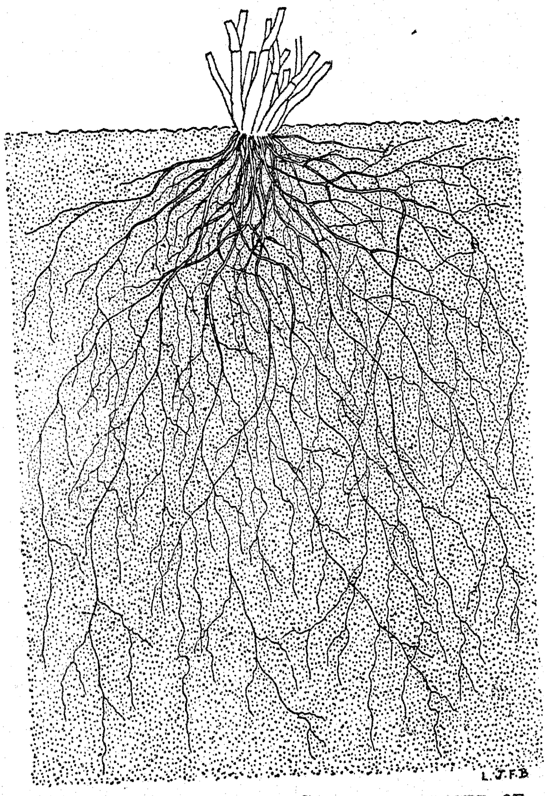


FIG. 22. FIBROUS ROOT SYSTEM, COMPOSED OF ADVENTITIOUS ROOTS, IN A GRASS.

leaf is usually given off at the node at an oblique angle ; seldom at right angles. The angle which the leaf makes with the stem is called the **axil**, and borne in the axil almost invariably is a bud, which is called the **axillary** bud as distinct from the terminal bud. These buds often grow out and produce branch stems (Fig. 24).

That part of the stem between one node and an adjacent node is called the **internode.** Appendages such as leaves are never

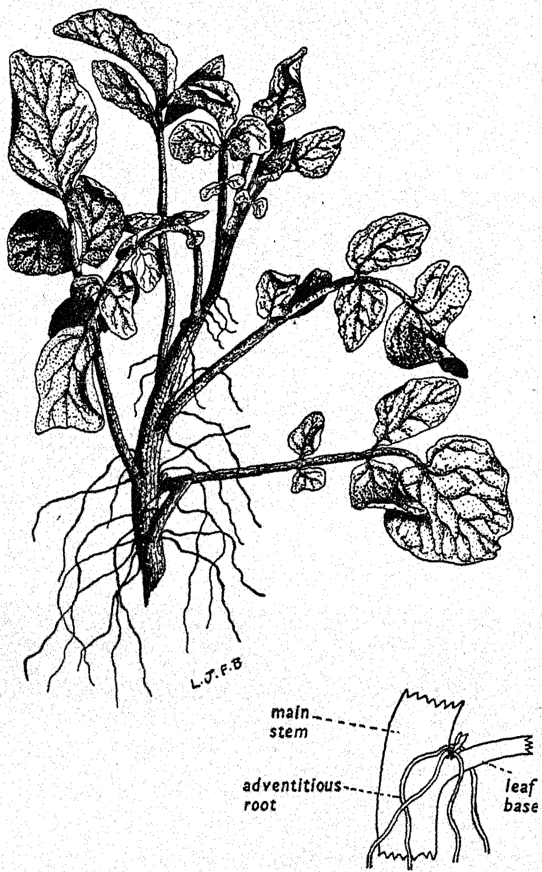


FIG. 23. PART OF A SHOOT OF WATER-CRESS, SHOWING ADVENTITIOUS ROOTS BORNE ON THE STEM. ON THE RIGHT, A LEAF AXIL ENLARGED.

given off on an internode. In some plants, such as the poppy and buttercup, the internodes are often covered with fine silky hairs (Fig. 19).

Buds are young, undeveloped shoots. If they are leaf buds only, they finally grow out to produce branch stems bearing leaves. If they are flower buds, on the other hand, they finally produce the flower, and then their growth is stopped. The pro-

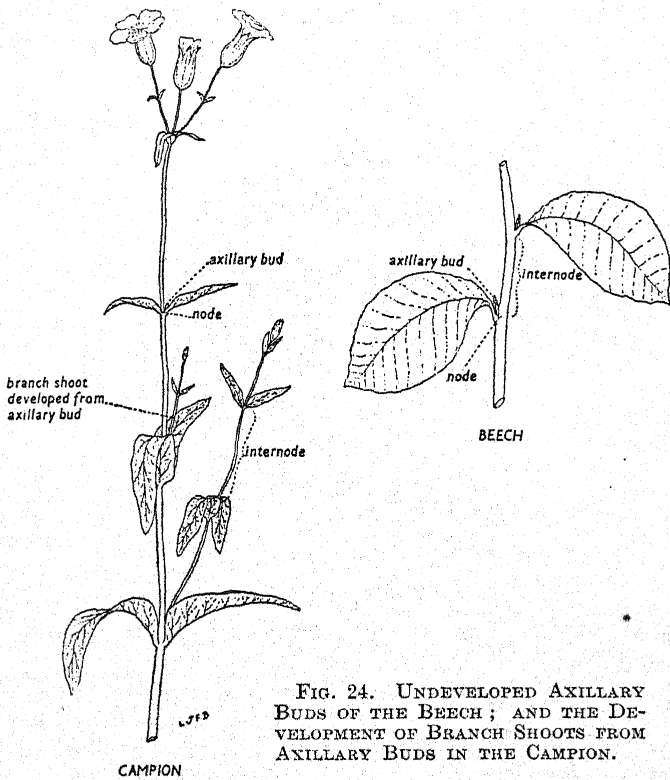


FIG. 24. UNDEVELOPED AXILLARY BUDS OF THE BEECH; AND THE DEVELOPMENT OF BRANCH SHOOTS FROM AXILLARY BUDS IN THE CAMPION.

duction of a flower always stops growth in that direction. Axillary buds sometimes produce branch stems, but not all such buds develop. Take, for example, the average tree. Considering the number of leaves, if all their axillary buds developed to produce branches, the tree would soon become a tangled mass. Such buds which remain asleep are said to be **dormant**. In exceptional circumstances, however, dormant buds will awaken and actively

develop branches. This is so in the case of the severing of a terminal bud. If the terminal bud is cut off or injured so that it cannot develop itself, then some of the dormant axillary buds develop. However, this is not common. If the main trunk of a tree, such as the oak or elm, be cut down or broken down, a dense outgrowth of branches develops from the base of the shoot. These branches are produced from dormant and adventitious buds. This is called **tillering** (Fig. 25). In some gardening

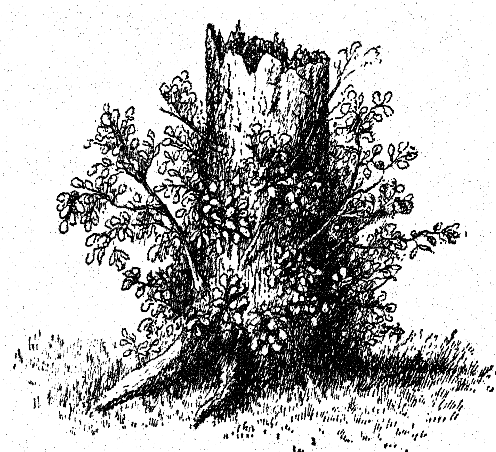


FIG. 25. TILLERING OF THE STUMP OF AN ELM TREE.

processes, such as nipping off the tips of runner beans, etc., the axillary buds are made to develop more quickly.

Pollarding and Coppicing

Closely related to this effect are the processes known as **pollarding** and **coppicing**; but these cases are not concerned with dormant buds. Dormant buds are there all the time, whether they develop or not. On the other hand, there are adventitious buds which develop in unusual places like adventitious roots. They are not axillary and when they do occur, which is not often, it is usually on trees. The process of pollarding is not common in Great Britain. It consists in lopping off the top of a tree and leaving just the trunk or bole. This is sometimes done with

willow trees growing along the banks of rivers (Fig. 26). When the top is lopped off, adventitious buds arise, where there were no buds before, usually near the edge on the cut end of the trunk. They develop into branch shoots, and give the tree a very weird appearance.

This fact is made use of in the case of the osier willow. When this willow is pollarded, it gives off, near the top, dozens of long,

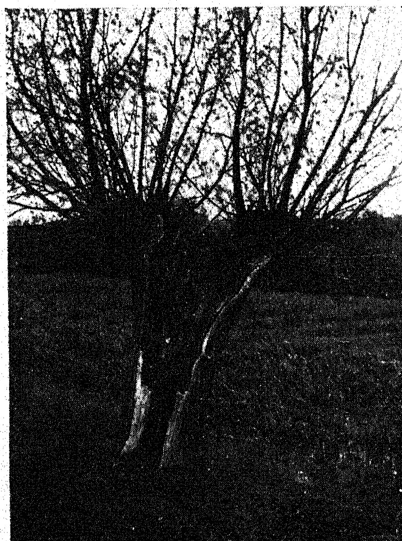


FIG. 26. AN OLD POLLARD WILLOW.
(*Photo. Flatters and Garnett, Ltd.*)

slender and tough branches from adventitious buds which arise in that position as the result of the pollarding. Osier willows are grown in low-lying, water-logged soils, and the young branches or osiers are used in basket-making and other wicker work. This industry flourishes on the Continent, and to some extent in Great Britain in the Fen district and the Thames valley. Ash trees are pollarded to a considerable extent in Algeria, and the resulting very young branches are used as forage for camels and horses.

Coppicing is very similar to pollarding except that, instead of lopping the tree at the top of the bole, it is lopped off at the base, near the ground. This is done to a considerable extent in Great Britain with hazel and alder. It produces very bushy trees, and when growing closely together they form a very thick copse, which is used as a covert for game birds and other animals for hunting purposes.

Growth in Thickness

Many plants, especially perennials, could not continue growing in length without some attempt at growing in thickness, else the plant would become so long and slender as to be unable to remain upright. Therefore, such plants, as they grow in length, also grow in thickness in such necessary parts as the stems and roots, only, of course, not at such a quick rate (see Chap. IX).

Nearly all stems and roots contain a certain amount of wood, and when these stems begin to thicken they do so chiefly by the formation of more wood in those organs. This growth in thickness is called **secondary thickening.** Trunks of trees, which are nothing but thickened stems, are thus composed chiefly of wood produced by the process of secondary thickening (Fig. 27).

The Trunk

If the trunk or a thick branch of a tree be cut across, the cut surface will reveal to what extent the deposition of wood has taken place in the stem. The wood forms the chief part of the thickened stem and it may be seen to be composed of two sections, that in the centre, which is of a dark colour, called the **heart** wood, and a lighter portion of wood surrounding it, called the **sap** wood. The heart wood is darker because it is dry and contains no sap. Therefore, the supply of sap, which is composed of water and dissolved mineral substances from the soil, passes up to the rest of the tree, through the sap wood only (Fig. 28).

Every year, during the growing season, which is from spring to autumn in temperate countries like Great Britain, the tree develops a thin layer of wood, which is added on to the outside of the already existing woody cylinder. No new wood is formed

during the winter. As will be seen in Chap. V, the wood is composed of a series of tubes, and when the stem is cut across these tubes look like many small circles. If the cut end of the trunk be examined with a pocket lens, the circular ends of the tubes will

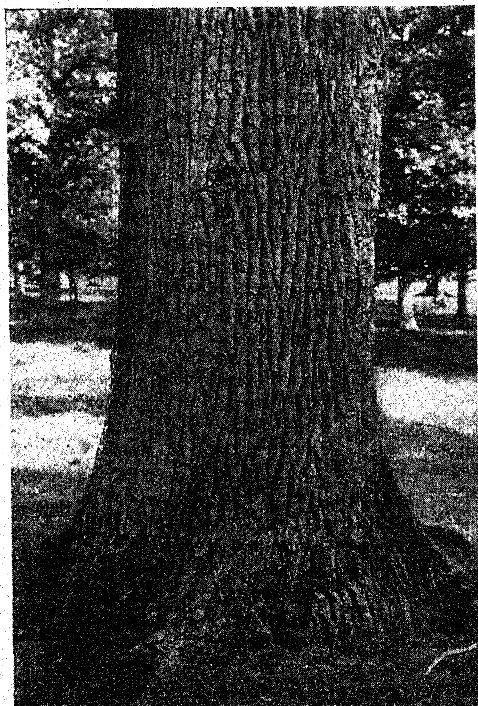


FIG. 27. TRUNK OF THE OAK, SHOWING A VERY MUCH THICKENED STEM.
(*Photo. Henry Irving.*)

clearly be seen. The tubes which are produced at the beginning of the growing season—that is, during the spring—are much larger than those produced towards the end of the season—that is, the autumn. Then growth ceases during the winter. The following spring sees more large tubes produced, and therefore between each season's growth there is a definite distinction, giving the

complete cut section of the trunk an appearance of concentric rings (Fig. 29).

Each ring represents one year's formation of wood and the rings are therefore called **annual rings.** Furthermore, some annual rings are wider than others, thus showing that during that year the tree experienced very good growing conditions.

Annual rings are very useful in forestry (see Chap. IX) and even in meteorology (the study of climate and weather). By

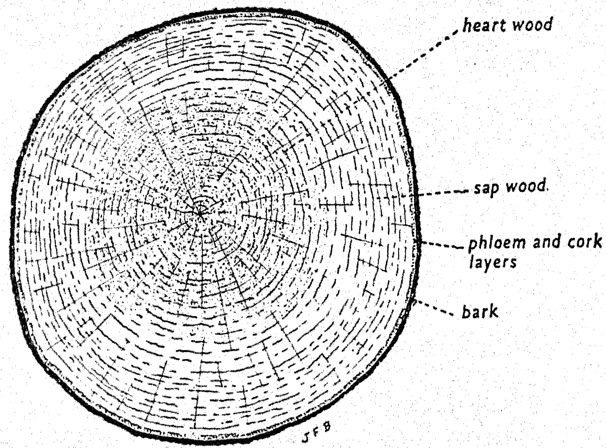


FIG. 28. TRANSVERSE SECTION OF A YOUNG TREE TRUNK, SHOWING THE HEART AND SAP WOOD.

counting the number of annual rings, which is a comparatively easy matter, it is possible to tell the age of the tree. That, for example, in Fig. 29 is eleven years old. One cross section of the trunk of a Californian redwood tree, which can be seen in the British Museum (Natural History), South Kensington, shows 1335 annual rings. Therefore, this trunk must have been obtained from a redwood tree 1335 years old. Also, by examining the comparative growth of the rings, it is possible to deduce the kind of weather of several years back.

This idea has been carried still further by an American scientific worker, Dr. A. E. Douglas, who took some fossilised trunks

of trees that must have existed on the earth millions of years ago and, by a special method, examined the annual rings in detail. From his results he was able to deduce many interesting facts concerning the climate and geology of the district whence the fossil trunks came, of many years ago. Dr. Douglas has also made some important discoveries concerning the climates of

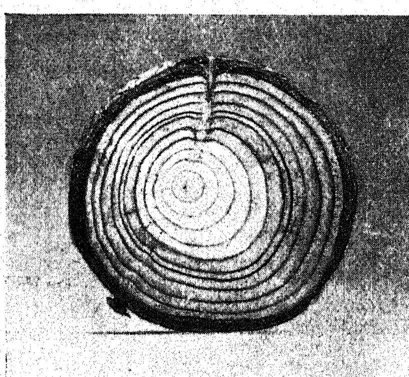


FIG. 29. TRANSVERSE SECTION OF A LARCH STEM, SHOWING ANNUAL RINGS.

more recent times by studying the size and shape of the annual rings of trees. For example, by this method he has shown that in the United States there was a great drought which commenced in 1276 and lasted for twenty-three years.

Timber

Timber or wood is used commercially for all kinds of purposes, many of which are familiar to us. It is used as a fuel and for all kinds of constructional purposes, the use to which it is put depending on its hardness and durability ; for these properties vary considerably in different woods. Wood is also used for the extraction of various chemicals, including wood alcohol and spirit.

The ash produces a tough wood, but since it is very elastic and 'gives' it is not used for building purposes. On account of its elastic nature it is used in the making of cricket bats, for it 'gives' and thus reduces the tingling sensation one feels if one

succeeds in hitting a very fast ball. For a similar reason, ash is used in the making of aeroplane propellers, so that it may withstand wind resistance.

Beech is a peculiar wood in that it cannot stand serious changes in humidity—that is, alternations of wet and dry conditions. It is therefore used as an indoor wood. Nevertheless, it can stand continued humidity and is therefore used in piles of piers and jetties. It takes a poor polish and is therefore not popular for household furniture.

Cedar wood is used extensively as a veneer in furniture-making, since it takes a good polish and is beautifully marked. Insects seldom attack it and therefore antique chests, which were sometimes made from it, are valuable to-day.

Ebony is a familiar wood in certain ornaments. It is almost black in colour. Only the heart wood is used commercially. The tree is cultivated for the purpose, chiefly in India.

Elm is very liable to warp and is therefore not much used. The elm tree, however, is often grown for ornamental purposes in avenues, etc., and in Italy the grape vines are trained up elm trees. The **wych elm**, which grows in Scotland and the North of England, has a tougher wood which, when properly seasoned, is very pliable. It is therefore used in building boats.

Maple takes a good polish and is extremely hard. It is therefore used very extensively in the building trade for floor-making, especially block and parquet floors.

Oak, being hard and nicely marked, is popular for furniture-making and panelling.

Pine and **deal** are characteristic soft woods. They are easy to work in the carpenter's shop and are used to a certain extent in making the cheaper forms of doors and panelling.

Teak, a tropical wood, though easily worked, is exceedingly hard and strong. It is used to a great extent where it will be exposed to the vagaries of water, acids, burns, etc.; hence its almost universal use for laboratory benches. It is a very heavy wood, its specific gravity being greater than that of water.

Walnut has exceedingly beautiful markings and takes a high polish. Hence its use in furniture-making. **Mahogany**, too, is used for a similar reason.

Fuels

Fuels produced from wood are very common. Besides being a fuel in itself, wood is the source of other fuels. **Charcoal** is produced by the dry distillation of wood, and its production by means of charcoal fires was at one time common in the British Isles, and still is in Austria and France.

Peat is the result of the activity of certain bacteria on plants, especially the woody parts. The activity of these bacteria is greatest in acid soils; hence the extensive peat bogs of Ireland and the Somersetshire plain. Peat is used largely by the peasants for their fires.

Coal originated primarily from wood. It is produced by long-continuous high pressure with great heat. The coal seams which may be seen in collieries were once great prehistoric forests of trees, belonging chiefly to the pteridophytes (see also Chap. XIII).

Bark

Surrounding the woody cylinder in the thickened plant stem are two other important layers, both of which, though not so extensive as the wood, are visible to the naked eye. There are others, however, which are not easily seen; for example, immediately surrounding the wood is a very thin layer called the **phloem**, down which the foods, manufactured by the green leaves, pass to the rest of the plant (see Chap. XII). Outside this, however, is a light brown layer of **cork**, which, in most trees, is rather thin. Outside this layer again, we have the outermost layer of the stem, the **bark**. This layer varies considerably in thickness and texture. Many trees therefore can be identified by their bark. The bark of the elm, for example, is thick and broken up, giving a wart-like appearance, whereas that of the beech is thinner and smoother. The bark of the plane tree is so thin that it naturally peals off in patches, leaving the yellowish tissues beneath exposed.

Cork

The cork of certain trees is of great commercial importance, owing to its impermeability to water. The cork oak (*Quercus*

Suber) is the chief source of cork, since the cork layer is very thick. This tree grows in parks in Great Britain, but it is cultivated for the purpose, especially on the Mediterranean coasts. The cork is stripped off in July and August by making transverse incisions in the trunk near the base and at intervals up the trunk towards the branches. Then longitudinal incisions are made and the sections removed.

Rough cork is used in the making of arbors and bowers in gardens. Fine cork is used for making bottle corks, cork lino and matting. Cork has been an article of commerce for centuries. It was one of the materials used in making the expensive coffins of the Egyptian kings and queens and was also used by the ancient Greeks as floats for fishing nets, bottle stoppers, and women's footwear. In Great Britain, even so far back as the Middle Ages, it was used as a lining for slippers. To-day it is used for several constructional purposes owing to its being a bad conductor of heat and sound.

The Twig in Winter

The examination of a twig during the winter reveals other interesting characteristics of the plant. For example, the **scars** of the leaves which have been shed may clearly be seen. They are either crescent- or horseshoe-shaped, and on them even the small scars of the veins which pass up into the leaf may be seen (Fig. 30).

A twig in winter affords a splendid opportunity of examining buds, as, for example, those of the horse-chestnut. The bud is often covered with a glutinous material as a protection against excessive moisture, which would get into the heart of the bud and make it rot. The outmost **bud scales** are boat-shaped and are used for protecting the tender foliage leaves inside. If all the scales and leaves are dissected from such a bud, it will be seen that there is no line of real distinction between the bud scales and the young foliage leaves, but that the one gradually merges into the other (Fig. 30).

Bud scales, like foliage leaves, leave their scars after they have fallen. These small **scale scars**, left after the terminal bud has grown out, form a ring around the stem (Fig. 30). At the end of

the next year, another ring is formed and so on. Therefore, the distance between one ring of scale scars and the next represents the amount of growth in length of that twig, for one year.

By this means, it is easy to tell which are the best districts for the growth of trees. Some time ago, a twig of horse-chestnut

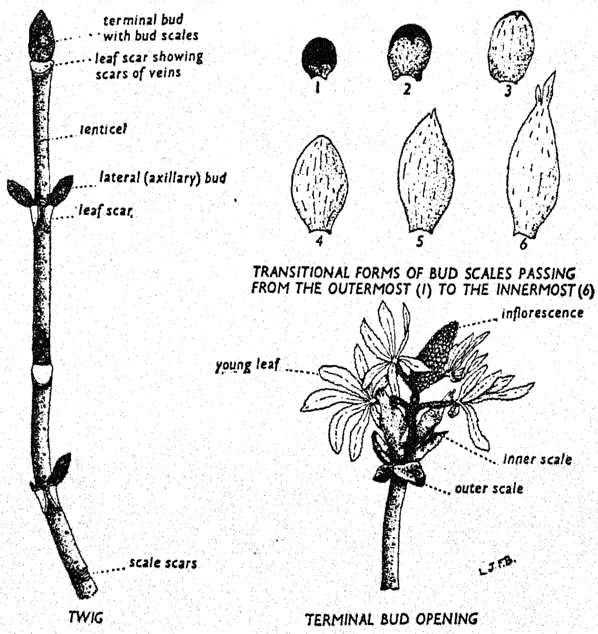


Fig. 30. A Twig of Horse-Chestnut in the Resting Stage and just beginning Development.

from the Mendip Hills in Somerset and another *of the same length* from the Botanical Gardens of Glasgow were examined. The number of rings of scale scars on the Mendip twig was two; therefore that twig had grown that length in two years. On the twig of the same length from Glasgow there were nineteen rings. Therefore, on the Mendip Hills the tree can grow about nine times as quickly as it can in Glasgow. This is due no doubt to

the fact that the atmosphere in Glasgow is more sooty and the temperature not so suitable for growth.

Other marks on the young twig are small dots all over the surface, scarcely bigger than a pin's point. They are usually lighter in colour and are composed of microscopic particles of cork, very loosely packed so that the whole area is porous. Anything that is porous will allow gases to percolate through, and that is why these small areas are porous.

As will be seen in Chap. XIII, nearly all plants take in (**inhale**) oxygen and give off (**exhale**) carbon dioxide, and so do nearly all animals. In the case of land-living plants and animals, this interchange is a gaseous one.

Now such gases cannot pass through solid cork quickly enough, and we have seen that such a layer does exist in a thickened stem; hence the spongy areas in the form of dots on the twig's surface. They are called **lenticels**, and form a passage for gaseous interchange (Figs. 30 and 31). As we shall see, however, in Chap. X, lenticels are not the most important organs present in the plant for gaseous interchange.

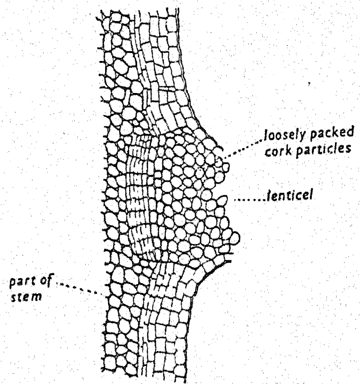


FIG. 31. TRANSVERSE SECTION OF PART OF OUTER PORTION OF THICKENED STEM, PASSING THROUGH A LENTICEL.

The Leaf

Leaves vary considerably in size and shape in different plants. There is the comparatively small leaf of the privet, and in contradistinction to this there is the banana leaf (Fig. 59), which is roughly the same shape but hundreds of times larger, being anything from one to three yards long.

The different shapes of leaves is best learned by collecting them and drawing them. One should be able to recognise a simple privet leaf or tulip leaf with its smooth margins,

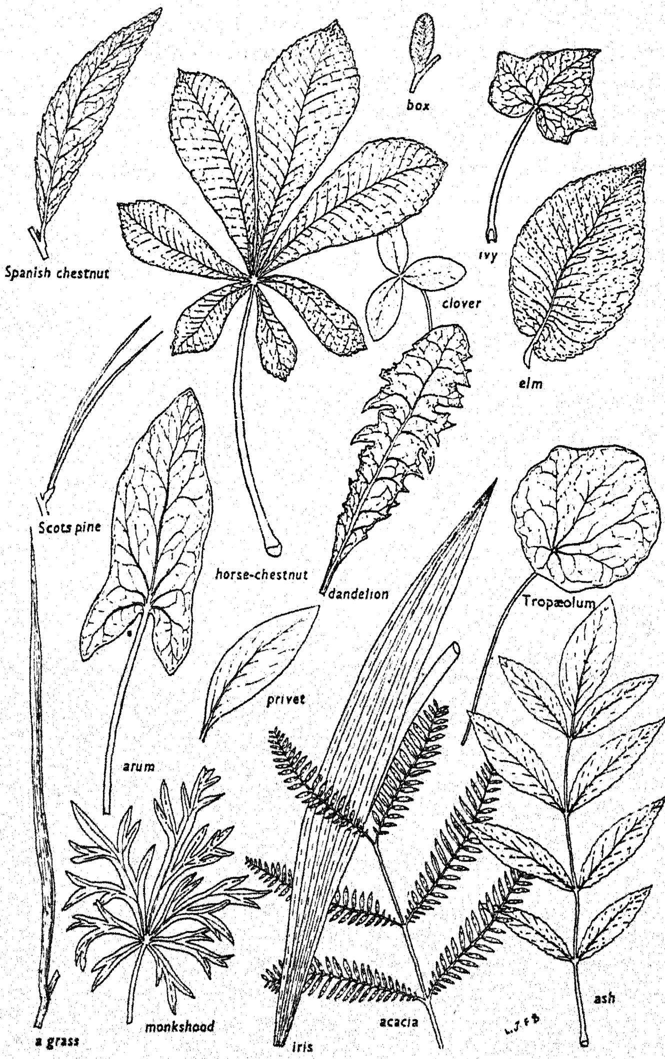


FIG. 32. TYPES OF FOLIAGE LEAVES.

the elm leaf with its serrated margin, the oak leaf with its deeply indented margin and the compound rose leaf, etc. (Fig. 32).

The typical leaf is composed of a **leaf stalk** or **petiole** which widens at its base, where it joins the node, into what is called the **leaf base.** Sometimes the leaf base is merely a thicker structure, as in the case of the horse-chestnut, or it may become elongated into a sheath as in the buttercup. In grasses, this sheath folds over the stem for a considerable distance.

The main flattened portion of the leaf is called the **leaf blade** or **lamina.** Sometimes the leaf blade is joined on to the leaf base, without the intermediate petiole, in which case the leaf is said to be **sessile.**

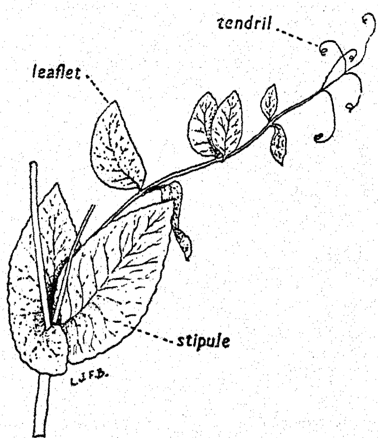


FIG. 33. LEAF OF GARDEN PEA, SHOWING THE LARGE STIPULES ON THE LEAF BASE.

Very commonly, wing-like outgrowths arise at the base of the petiole, one on each side, and appear like small leaflets. These may be seen in the rose and, still better, in the pea (Fig. 33). These outgrowths vary considerably in shape, size and function and are called **stipules.** In many plants, stipules are absent—for example, in the privet. In others, they are used for protecting the bud as in the case of the beech.

It is in the lamina that leaves usually show their great diversity of form. On the lamina, thicker lines called **veins** are visible. These are channels for conducting water to, and food from, the leaf (see Chap. XII). These veins give off finer branch veins, then these branch veins give off still finer ones, and so forth. The whole arrangement of the veins is called **venation.** The venation already described is **net** or **reticulate.** In other cases, especially the blade-like leaves of grasses, lilies, irises,

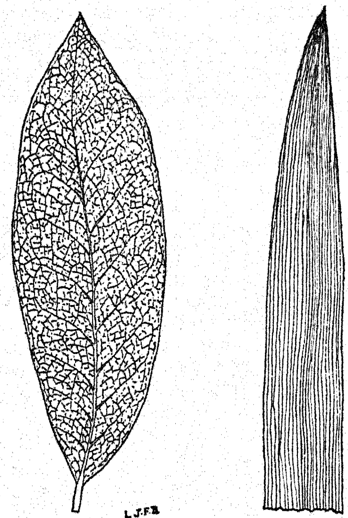


FIG. 34. LEFT, a *Rhododendron* LEAF, SHOWING NET VENATION; RIGHT, UPPER PORTION OF AN *Iris* LEAF, SHOWING PARALLEL VENATION.

etc., instead of having a main vein with branches, there are several veins, equal in size, running parallel to each other. This is known as **parallel** venation (Fig. 34).

In many leaves, despite diversity of shape, the whole lamina is one single structure, as is the case in the oak, elm, dandelion, tulip, etc. Such a leaf is said to be **simple.** In other cases, the indentation of the margin to varying degrees has gone so far that the lamina is cut up into several parts or **leaflets,** as seen in the horse-chestnut, rose, and ash. Such leaves are said to be **compound** (Fig. 32).

PRACTICAL WORK

General Directions

In the study of plant life, practical work is quite as important as theoretical study from a book; but it is essential that the practical work should be carried out thoroughly. One should try to find out things for oneself during such work, and then use the text of the book as a means to understanding what has already been observed. Practical work should never be treated as a supplement to theoretical study.

No practical work should be done without keeping a permanent record of it, either by diagrams, written description, or both. Such records should be made at the time, either in the laboratory or field. Diagrams, etc., can be 'touched up' afterwards, in the class-room or study; but things should never be put aside. Just as a policeman makes a written report of an accident, as soon as is possible, at the scene of the accident, so should all practical work

be reported by diagrams and written description while the work is progressing.

Written descriptions should always be clear, full, and to the point. Diagrams, too, should be very clear. Although it is desirable to bring in artistic effect in order to make the diagrams neat and attractive, such effect must invariably be subsidiary to clarity, and the portrayal of the true facts. For this reason, it is usually desirable to use line diagrams. Avoid shading and, so far as is possible, use pencil, and not ink. Colours, either by means of crayons or wash, should be used very sparingly. Only an artist of exceptional talent can hope to bring out the details in the structure of a flower, for example, by wash, of a sufficiently high standard to satisfy the discerning botanist. Great care should be taken over the diagrams. They should always be very large—much larger than those used to illustrate the text of this book.

A diagram, however faithfully and nicely drawn it may be, is utterly useless unless it is fully labelled. One should be able to revise one's work from the diagrams, and this would be impossible if they were not labelled. The best method of labelling is the one used chiefly in this book. Labelling by means of letters with an explanatory legend at the bottom of the diagram, is not desirable, since constant reference to the legend is irritating and unnecessary.

No diagrams should be copied from the book. Those in the book are given as a help in following the text, and also a *guide* during practical work. But they must be used *only* as a guide. Draw exactly what is seen, and then, with the help of the book, label carefully.

A written description is also a splendid means of driving home important points. Where the study of plant structures are concerned, the written description is not essential, provided good drawings are made ; yet it is well worth while. In experimental work, of course, the written description of the experiment, method, results and conclusions, are absolutely essential.

In the following practical work, and, indeed, in all the practical work throughout the book, only suggestions are made. Much is left to the choice of the reader. For example, one need not necessarily choose the plant material suggested. Perhaps other material, just as good, and probably better, is easily available ; then there is no reason why it should not be used. In the experimental work, the reader might think of a different method of performing an experiment. In fact, it is worth while trying to think of other methods. Then, provided one is quite sure that the different method will be just as good, there is no reason why it should not be applied.

Finally, the amount of practical work suggested throughout the book, forms neither the maximum nor the minimum. If more work can be done, then do it. If time will not allow for all of it to be done, then a wise choice must be made.

For detailed structure, a hand lens should always be used.

1. Make a thorough examination of the external features of a herbaceous flowering plant. Good specimens for this purpose are, the common buttercup (*Ranunculus acris*), wallflower (*Cheiranthus Cheiri*), and the groundsel (*Senecio vulgaris*). Note its division into root and shoot, and carefully observe the structure of the stem, leaf, axillary and terminal buds, and flower. Note also the nodes and internodes. Make a fully labelled drawing of the plant and, if time will permit, write a description of the plant.

2. Make enlarged drawings showing all the details of the most important parts of the plant, such as the root system, node, leaf, etc.

3. Examine and draw a seedling, noting especially the root hairs. A small tree seedling, such as that of the sycamore (*Acer pseudo-platanus*), will do. In this case, carefully wash all the soil from the roots in order to expose the root hairs.

A more convenient seedling to use is that of the mustard (*Brassica nigra*), for this can easily be cultivated by sowing some seeds on damp blotting paper or cotton wool and the seedlings, which develop in the course of a few days, can be examined without handling them.

4. Examine, draw, and describe various root systems ; tap root (wallflower, groundsel), fibrous (a grass), and adventitious (water cress).

It is also interesting to watch the development of adventitious roots on the twig of the willow (*Salix alba*). The twigs should be gathered late in winter, and placed in a vessel of water. In a few weeks, the buds will open, when their progress can be watched with profit, and adventitious roots will appear on the stem. Keep a dated record of the progress of the shoot, and draw examples of the adventitious roots.

5. Examine and draw a section across a tree trunk. It is usually possible to do this in the field, where a tree has fallen and the trunk severed ; otherwise, the sawn end of a fairly thick branch may be used. The end could then be smoothed and polished, making the structure more easily seen. Note especially, sap wood, heart wood, annual rings, cork and bark.

6. Investigate and record the properties (hardness, colour, specific gravity, general appearance, etc.) of various types of wood. One should learn to be able to recognise woods of general economic importance. Make comparative drawings of them. Examples may be chosen from those mentioned in the text.

7. Make a careful study of a twig in winter. Several examples should be chosen, such as oak (*Quercus Robur*), ash (*Fraxinus excelsior*), horse-chestnut (*Aesculus hippocastanum*), etc. Note especially the bark, lenticels, leaf scars, scale scars and buds. Make careful drawings to show these various structures, and also compare and contrast the various types.

Examine the bud scales by dissecting the bud. Note the transition from bud scale to foliage leaf, and arrange and draw the examples in series.

Keep some winter twigs in water and note and record steps in the development as they open.

8. Examine, draw and describe, different types of foliage leaves. Some examples may be taken from those illustrated in Fig. 32, but there are many other types. Note also the stipules of certain leaves such as the rose, pea, etc. Parallel and net venation can easily be seen in many common types of leaf.

Field Work

The joys of the countryside can be very much increased by taking an intelligent interest in the flora. It is not absolutely essential to attend field classes or natural history rambles, in order to do this. A sketch-book or a camera, or both, and a fine day, can give many hours of profitable pleasure. Not only that, but there is often a more immediate utilitarian value attached to such a hobby. Schools, societies, country flower-shows, etc., offer prizes for the results of various types of field work, and the work entailed in such competitions has more far-reaching consequences. The type of work undertaken must rest with the tastes of the individual, or the conditions of any such competition; but throughout this book, ideas for such hobbies should easily be gleaned. For example, in connexion with Chap. III, drawings, or photographs of trees in winter and summer, form a good collection. On the drawing or photograph should be indicated detailed information, such as name of the tree, date, place, and so forth. A written description, too, is desirable.

Photographs of examples of pollarding, coppicing and tillering, should also be obtained.

Making collections of leaves, an old-established hobby, may prove, and has proved, a waste of time. On the other hand, it can form the basis of a profitable pursuit. The usual method is to collect suitable examples, place them between sheets of blotting paper and then press in a book for several weeks. Then the pressed, dried specimens are mounted with either gum or adhesive tape on stout paper, or Bristol board. If the pursuit stops there, it is practically valueless. To make it more interesting, and certainly very valuable and instructive, details of the name, date, locality, type, etc., should be written on the mount. A short description, too, is useful, and a small diagram (also on the mount) is worth while.

CHAPTER IV

SPECIAL FORMS AND FUNCTIONS OF PLANT ORGANS

IN nearly all cases, plant and animal organs are developed to perform certain definite functions, and they are usually so constructed that they may perform their work satisfactorily. For example, the function of the eye in the animal is to enable that animal to see. The structure of the eye of most animals is similar to that of a camera. There is a recording surface called the **retina**, which corresponds to the film or plate in the camera, and in front of this there is a **lens** which makes miniature pictures or images on the retina.

All plant organs have a general function to perform; but many have *special* functions and are modified accordingly. The best way of examining the various special modifications of plant organs will be to take each organ, see the special modifications and then deduce what are its special functions.

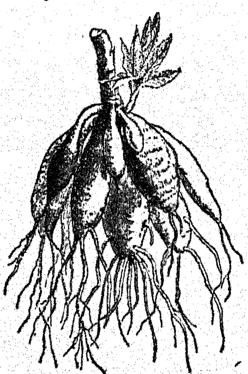


FIG. 35. ROOT TUBERS OF DAHLIA. (*After Figuier.*)

Modifications of the Root

The plant very often manufactures more food than it can utilise immediately. The excess food, therefore, has to be stored. Such food storage takes place chiefly in perennials, in order to tide the plant over the winter, and to ensure its being prepared to begin the following season's activity.

Storage of food takes place in several organs, and in some cases it is the root. In order to form such a store cupboard, some roots become very thick, thus allowing

plenty of space for the stores of food. Such fleshy roots are called **root tubers.** We can tell they are really roots, for, just like normal roots, they do not bear leaves, they have the internal structure of the root, and at their tips they have a protective cap called the **root cap,** which all roots, but no other organs, possess (see Chap. VIII).

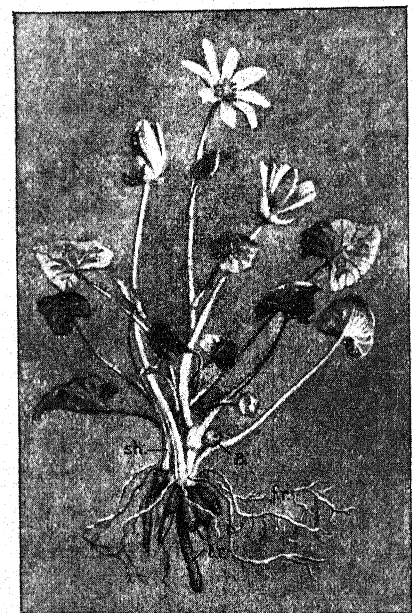


FIG. 36. LESSER CELANDINE.
t.r. Root tubers.

Root tubers are seen in the *Dahlia* and lesser celandine (Figs. 35 and 36), in which the food is stored in the form of starch, and in many orchids. In all these cases, the root tubers are adventitious roots. Swollen tap roots (which are not called tubers) are seen in the carrot and beet, both of which store food in the form of sugar, and in the parsnip and turnip, which store starch (Fig. 37).

In some plants, roots, instead of arising beneath the soil,

grow out adventitiously from the stem, and pass some distance through the air before reaching the soil. These are called **aerial roots.** They are seen in the banyan tree in the tropics, and they assist in supporting the long, spreading branches (Figs. 38 and 39). Other plants which grow in tropical mangrove swamps possess aerial roots, which are the sole support of the plant, for, after a time, the original stem rots completely away.

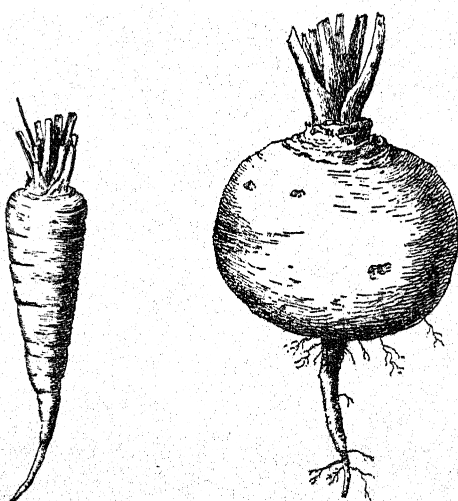


FIG. 37. SWOLLEN TAP ROOTS; CARROT, LEFT; TURNIP, RIGHT.

In some tropical orchids and other tropical plants, the stem gives off adventitious, climbing roots, by means of which such plants climb up other plants.

Other tropical orchids grow completely on trees, some distance away from the soil. From such plants, roots are given off which remain suspended in the air, and never touch the ground (Fig. 40). The exteriors of these roots are of a spongy texture, formed by the outmost layer which has lost its succulence and become filled with airspaces. This layer is called the **velamen** and is used as a great surface area on which moisture from the air is condensed, thus supplying the plant with the necessary water.

All roots, like other living structures, must have air for gaseous interchange. This is usually possible, for there is plenty of air in the small spaces between soil particles. However, in some cases, for example, mangrove swamps, the soil becomes so water-logged, or perhaps even submerged in water, that the aeration of the soil is impossible. In such cases, many plants

FIG. 38. BANYAN TREES (*Ficus bengalensis*) IN THE BOTANIC GARDEN, BUITENZORG, JAVA.
Note the long, thickened, aerial roots.

have exceptional root modifications. Some of these roots, instead of growing downwards, as roots usually do, grow upwards into the air. That part of the root exposed to the air becomes covered with lenticels. The roots are therefore **breathing or respiratory roots** (Fig. 41).

If you attempt to tear ivy away from a wall or a tree on which it is fixed, you will find that this demands considerable force. In this case, the stem gives off hundreds of adventitious roots

which cling tenaciously to the support. Such roots are called **climbing roots** (Fig. 42).

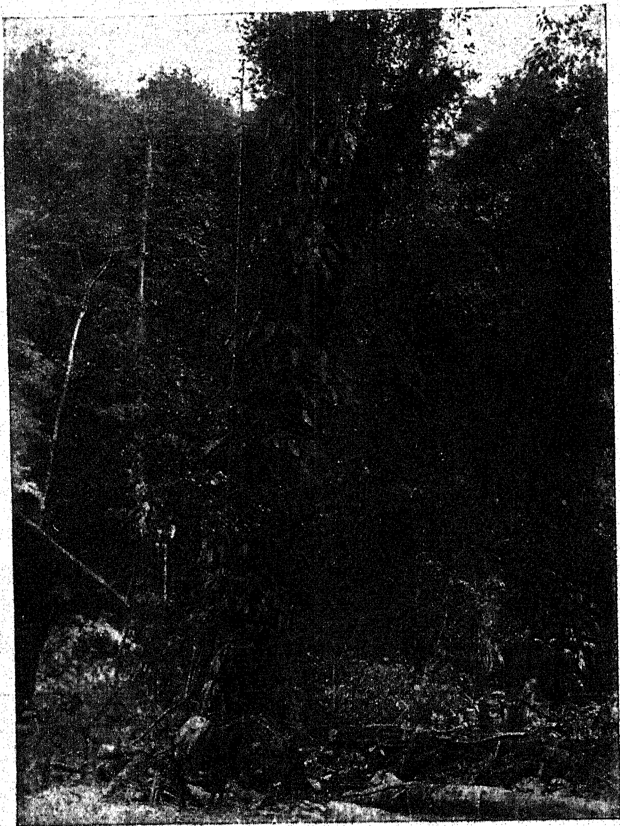


FIG. 39. SCENE IN A MOIST TROPICAL FOREST.

Note the hanging roots of root-climbing plants. These roots serve to nourish the plant, after the death of the stem.

In the maize plant and some others, even some trees and bamboos, the plant is very large with only a comparatively thin stem to support it. The risk of being blown over is prevented,

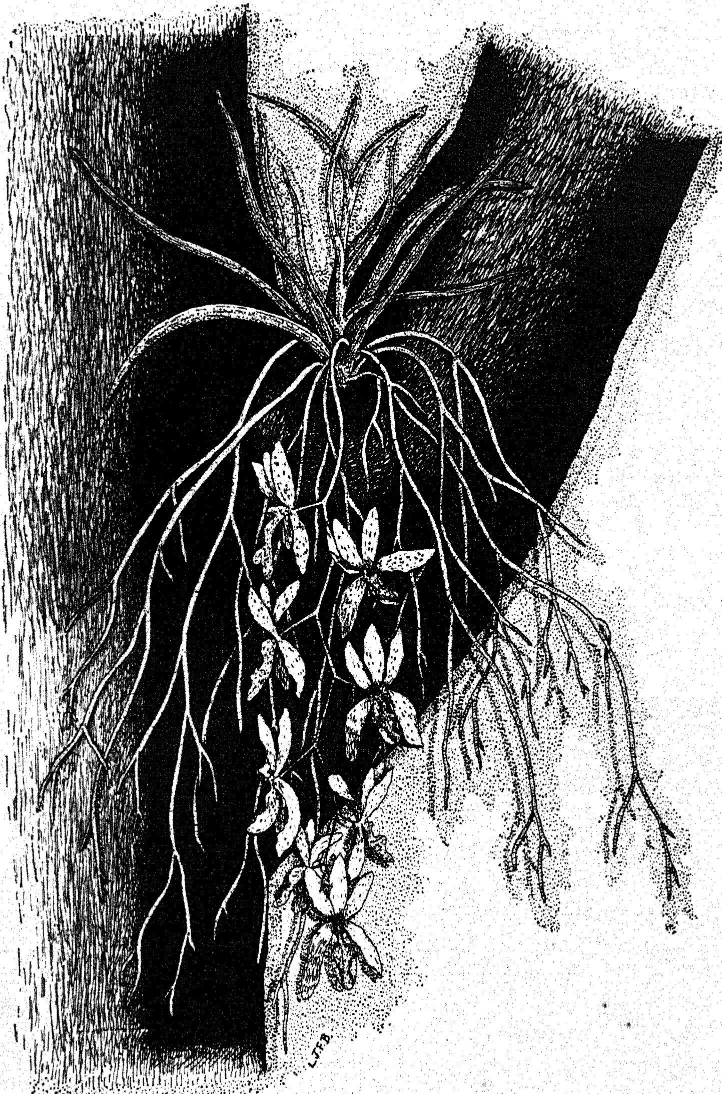


Fig. 40. A Tropical Orchid growing on a Tree.

Note the hanging inflorescence and moisture-absorbing aerial roots. For clarity, some of the leaves have been omitted.

however, by buttresses similar to the flying buttresses seen on some churches and cathedrals. These buttresses, in the case of such plants, are formed by adventitious roots, which, owing to their buttress or stilt-like appearance, are called **buttress** or **stilt roots** (Figs. 43 and 44).

Modifications of the Stem

Stems, like roots, are sometimes modified to form store-houses for food. Such stems swell in order to make room for this food.

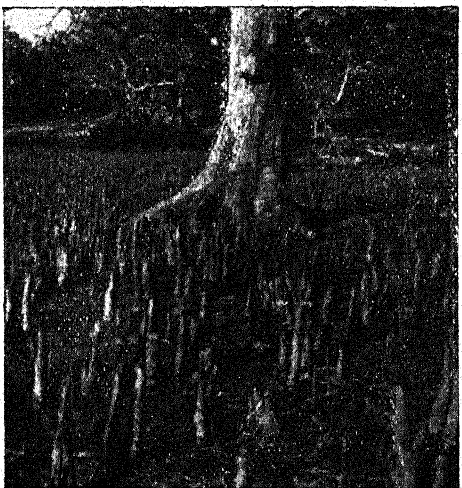


FIG. 41. BREATHING (RESPIRATORY) ROOTS OF *Sonneratia alba* IN A MANGROVE SWAMP.
(*After Joh. Schmidt.*)

Many cacti which grow in tropical deserts and are cultivated in greenhouses are of this character. The stems are sometimes cylindrical, sometimes slightly flattened, though always thick and juicy. These stems store water chiefly, as might be expected in such cases. Here they are also green, and carry out the functions of the green leaf. The leaves of such plants, therefore, are not wanted for food manufacture, and are modified into small, sharp spines, for protection against browsing animals (Figs. 45 and 46).

The normal stem of a plant grows vertically into the air, giving off its branches obliquely upwards. There are, however, some exceptions which are modified for definite purposes. Some creep along the surface of the ground, and others grow actually beneath it.

One such type, in the potato (*Solanum tuberosum*), is very familiar. The edible portion of the potato is familiar to us all,

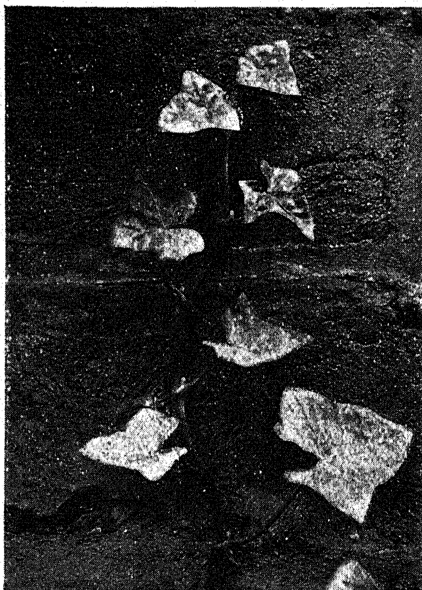


FIG. 42. IVY CLIMBING A WALL.
Note the adventitious climbing roots.
(*Photo. Henry Irving.*)

and everybody knows that it generally grows beneath the soil. Yet it is not a root, for it bears shoots, as may be seen when it is stored for several months in a warm, dark place, for it then 'shoots out'. These shoots develop from the 'eyes' of the potato, which are really young buds in the axils of insignificant scale leaves. The edible portion of the potato is therefore an **underground stem**, and is called a **stem tuber**. Underground

stems grow along from the potato plant and towards their tips they swell to form the tubers (Fig. 47). The food stored in this swollen organ is chiefly starch, with a certain amount of protein.

The potato tuber, however, is not only used for food storage. As has already been seen, seeds are a means of the reproduction of the plant. But they are not the only method available to the

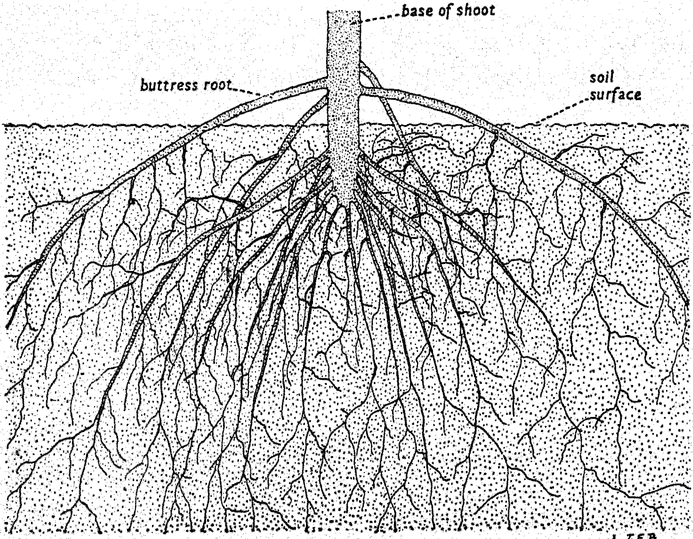


FIG. 43. PART OF THE ROOT SYSTEM OF THE MAIZE, SHOWING THE BUTTRESS ROOTS.

plant. All methods of reproduction in flowering plants other than that by seeds are called **vegetative reproduction.**

The potato tuber is a means of vegetative reproduction. The ordinary gardener never uses the real potato seeds for the production of new crops ; he uses the tubers, saved from the plants of the previous season. They are often called ' seed potatoes ', but actually they are not seeds, for *seeds are invariably produced by flowers.*

Whereas the seeds usually begin growth by the production of roots, the potato tuber, once it has been placed in the soil, begins

its growth by the production of new shoots. These are produced from the buds present in the 'eyes'. Each 'eye' sends off at least one shoot and that is why, for the sake of economy, 'seed potatoes' are often cut, for so long as there is an 'eye' and a certain amount of the fleshy part of the tuber present, a new plant can develop. The shoot goes on growing, getting the food that is necessary for its growth from the tuber, until it emerges above the soil. Then it unfolds new foliage leaves, which, since they are green, can manufacture a new supply of food. But these leaves must have a supply of water and mineral salts from the soil, and to prepare for this, those parts of the stems of the shoots which are below the soil give off adventitious roots. Thus the new plant becomes established in the soil (Fig. 48).

FIG. 44. BUTTRESS ROOTS IN *Rhizophora mucronata* IN A MANGROVE SWAMP IN THE MALAY ARCHIPELAGO.

(*After Karsten.*)

Another stem tuber similar to the potato is that of the Jerusalem artichoke (*Helianthus tuberosus*), which stores starch, and is therefore used as an article of diet. In this case, however, many adventitious roots are borne on the tuber itself (Fig. 48).

The crocus (*Colchicum*) supplies another example of a stem modified for food storage. It is, however, totally different from a potato tuber, since it is the main stem of the plant; there are no branch stems in the crocus. The swollen, food-storing structure in this case is called a **corm** (Fig. 50). It is clearly a stem since it has the internal structure of a stem and it bears leaves. Since, however, the corm grows beneath the soil, the

leaves cannot be foliar. They are thin and membranous and completely surround the corm itself. If these membranous scale

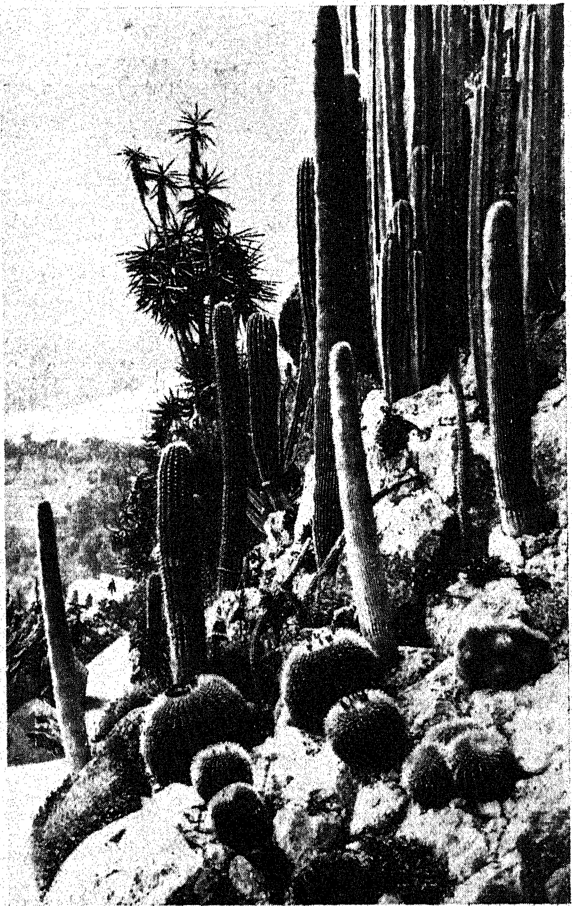


FIG. 45. CACTI IN THE EXOTIC GARDENS, MONTE CARLO, SHOWING THICK, SUCCULENT, WATER-STORING STEMS.
(*The Times, copyright.*)

leaves are torn off the corm, small axillary buds may be seen (Fig. 51).

In early spring, the terminal bud of the swollen stem, or corm, bursts forth, and produces a flower and green foliage leaves. Meanwhile, the base of one of the young axillary buds of a scale leaf begins to swell and produce the corm for the following year.

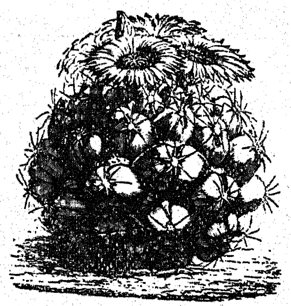


FIG. 46. SUCCULENT STEM OF A CACTUS, SHOWING ALSO LEAVES MODIFIED TO SPINES. (*After Figuier.*)

During the spring, food manufactured by the foliage leaves is passed to this young developing corm, where it is stored, and the old corm shrivels up and dies. After the plant's activity has ceased in late spring, the new corm remains in the soil, and thus the plant tides itself over the winter—as a corm, resting in the soil. This resting condition, during inclement weather, that is, the winter, is called **perennation.** The food stored is ready as a supply for the next season's outburst of growth. It is stored in the form of starch. The *Gladiolus* also possesses a corm.

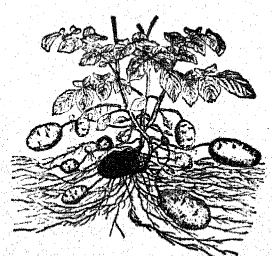


FIG. 47. PART OF A POTATO PLANT.

The plant has been reproduced vegetatively from the old, dark tuber. The new tubers show the characteristic 'eyes'. (Reduced.)

(*After Schenck.*)

There are many examples of stems which grow more or less horizontally beneath the soil but are not swollen. They have the same structure as the normal stem, but of course cannot contain chlorophyll like many of the latter. They are cylindrical and are composed of nodes and internodes. From the latter, leaves are given off, but naturally these cannot be foliar. They are usually reduced to insignificant, colourless, tissue-like scale leaves.

These underground stems are called **rhizomes.** At the nodes adventitious roots are given off, so that from the point of view of getting supplies of water and other substances from the soil, the stem could go on growing indefinitely. The buds in

the axils of some of the scale leaves develop and send up branch shoots which finally open out as normal shoots in the air and bear foliage leaves and flowers.

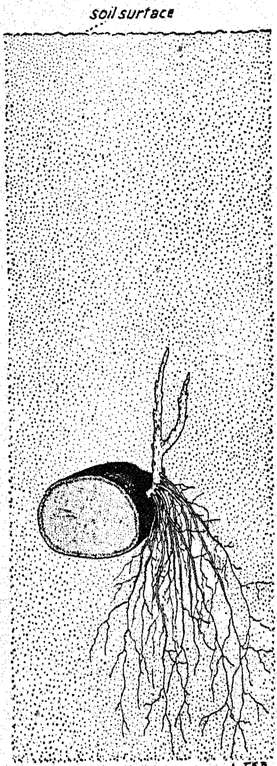


FIG. 48. HALF A POTATO TUBER DEVELOPING IN THE SOIL.

Note the young shoots, which have developed from an 'eye', pushing their way up through the soil. Adventitious roots are forming at the base of the shoots.

These foliage leaves thus ensure a supply of manufactured food, and therefore the rhizome can grow to considerable lengths in the soil, being independent of the original roots and shoots for supplies. Sedges possess such rhizomes (Fig. 52), so also does the couch-grass (*Agropyron repens*).

With these rhizomes, the plants spread rapidly. Owing to the tremendous length of their rhizomes, it is very difficult to eradicate the complete plants from the soil. Even if the rhizome were completely severed, both parts could live, since they have their own roots and foliage shoots. That is why couch-grass and bindweed are such bad garden weeds. Also many grasses with rhizomes are used for growing on loose sand dunes, since their rhizomes ramify through the sand and bind it together. The iris (*Iris pseudacorus*) and Solomon's seal (*Polygonatum multiflorum*) also possess rhizomes which are, however, swollen throughout their length (not like the potato, only in one part) and store food (Fig. 53).

Very similar to rhizomes are underground stems known as suckers. They differ, however, in that instead of being the main stem, like the rhizome, they are branch stems. An example of this is the mint (*Mentha*); hence the reason why this plant easily

spreads. The elm (*Ulmus*) and poplar (*Populus*) also give off suckers, but in this case the suckers, which are really the portions which grow above the soil, are given off from branch roots, and not branch stems.

Suckers are also produced by wood sage, white dead-nettle, yarrow, rose, hazel, apple, plum, etc. A plum tree, if severely pruned, sometimes produces suckers. This is often seen in gardens where plum trees are trained against a wall and con-

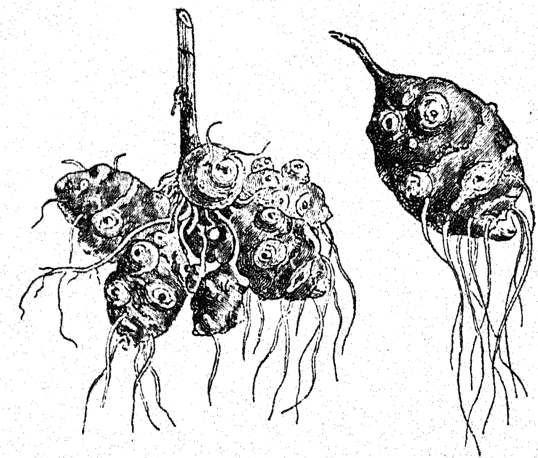


FIG. 49. STEM TUBERS OF THE JERUSALEM ARTICHOKE.
Note the adventitious roots produced on the tubers.
(*After Vilmorin.*)

sequently well pruned. Such suckers may be looked upon as a response to checking the development of the aerial shoot.

Suckers, after rooting, send up shoots into the air. Thus they become established, and eventually are able to develop into separate plants by the decay of the original branch connecting them with the parent plant. This is, therefore, a means of vegetative reproduction, and is sometimes used in horticultural and agricultural practice. The banana is another important example, for rarely does this plant bear seeds. On the other hand, unless the suckers are definitely required for the purpose of vegetative

reproduction, it is often necessary to prune them away, since they clearly rob the parent plant of nourishment which it would otherwise use for its own development.

In other cases, instead of the stem growing along beneath the soil, it grows along, in a recumbent position, on the surface of the soil. In some cases, such a trailing, **creeping stem** is a main stem.

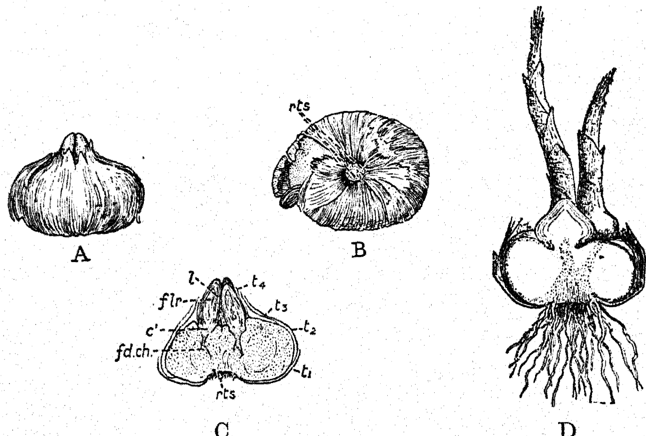


FIG. 50. CROCUS CORM.

A, from the side; B, from below; C, longitudinal section. A-C, winter resting stage. D, resumption of growth in spring. *rts*, young roots; t_1-t_4, scale leaves; *fd. ch.*, channels for passage of food from corm to bud; *flr*, flower bud; *c'*, base of bud beginning to swell to form next year's corm (better seen in D); *l*, young foliage leaves.

This is seen in the moneywort (*Lysimachia Nummularia*). The stem creeps along the soil, giving off adventitious roots at its nodes. Therefore, if the stem be severed, both parts can live (Fig. 54).

Often, however, the creeping stem is a branch. Such stems are known as **runners**, and a well-known example is that of the strawberry (*Fragaria vesca*). At the nodes of the runner, adventitious roots are given off and penetrate the soil. Once they are established, the axillary bud at the node develops to produce a foliage

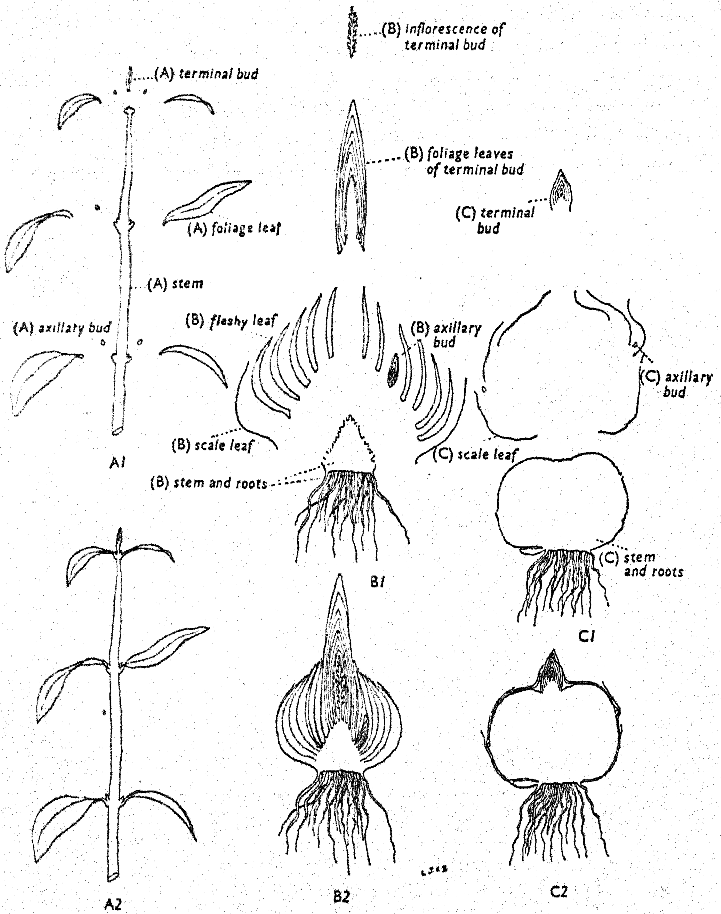


FIG. 51. DIAGRAM TO SHOW THE FORMS OF MODIFICATIONS IN A BULB AND A CORM.

A1, normal foliage shoot dissected; B1, bulb dissected; C1, corm dissected. A2, B2, and C2, the same organs assembled.

shoot. Thus, at the node, a new plant is produced (Fig. 55). Once the roots are established in the soil and the shoot has developed, the new plant becomes independent of the parent

plant, and it does not matter if the latter dies or the runner becomes severed.

This is, therefore, another means of vegetative reproduction, and is used artificially by gardeners for producing new strawberry plants. The runner is usually trained on to the surface of the soil in a pot, and once the new plant has become established

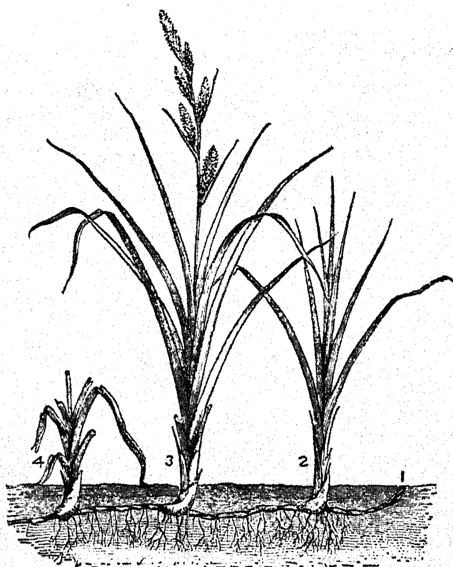


FIG. 52. RHIZOME OF SAND SEDGE.

1, terminal bud; 2, 3, 4, foliage shoots arising from previous buds. The rhizome continues growth in length from an axillary bud. Note the scale leaves and adventitious roots.

(*After Figuier.*)

in the pot, the old runner is cut. Runners are also produced by the daisy (*Bellis perennis*) and sweet violet (*Viola odorata*). In the houseleek (*Sempervivum tectorum*), the runner is extremely short and thick and produces only one new plant at its apex. This is called an **off-set** (Fig. 56).

Closely related to runners are **stolons**. These are normally growing branches which are not recumbent, but owing to their own

great length bend over and touch the soil. Where a node touches the soil, adventitious roots are given off into the soil, and the

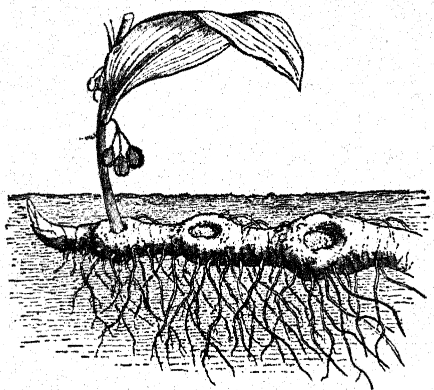


FIG. 53. SWOLLEN RHIZOME OF SOLOMON'S SEAL.
Note from left to right: bud for next year's erect shoot, current year's shoot with leaf and flowers, scar of last year's erect shoot, and scar of erect shoot of two years previous.
(*After Figuier.*)

axillary bud at that node grows out to produce a shoot. Thus is a new plant established by another method of vegetative reproduction. Once established it can safely be severed from

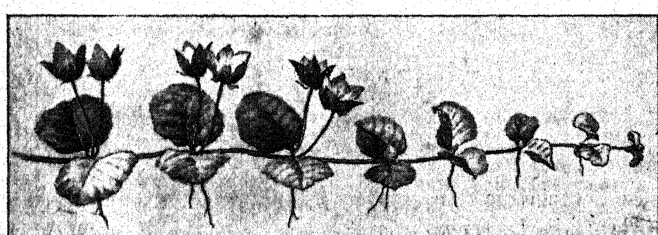


FIG. 54. CREEPING STEM OF THE MONEYWORT.

the parent plant by cutting the stolon. Stolons are present in the blackberry (*Rubus fruticosus*), currants (*Ribes*) and the gooseberry (*Ribes Grossularia*) (Fig. 57), and the gardener helps this vegetative method of producing new plants by

fixing the stolon to the soil by means of a small staple. The process is called **layering** (Fig. 58).

Plants which are quite harmless, or indeed useful, in some

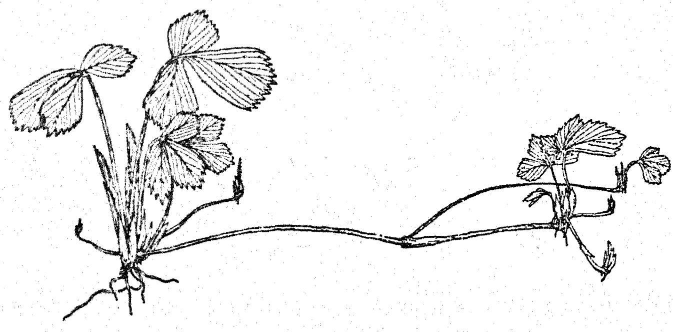


FIG. 55. STRAWBERRY PLANT BEARING AXILLARY BUDS DEVELOPED AS RUNNERS, WITH LONG INTERNODES WHICH MAY BRANCH AND ROOT AT THEIR DISTAL ENDS.

(*After Thompson.*)

countries, are absolute weeds in another. For example the blackberry can scarcely be looked upon as a pest in Great Britain, yet in New Zealand it is a real weed. There, it grows

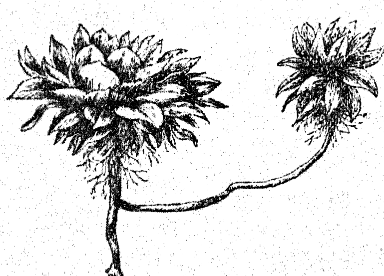


FIG. 56. OFF-SET OF HOUSELEEK.

and vegetatively reproduces itself prodigiously by stolons, and thus 'creeps' over arable and other cultivated land. One plant, by virtue of its stolons, has actually reached a length of 250 miles.

In the banana (*Musa sapientum*), the apparent erect stem is really nothing but closely overlapping bases of the enormous foliage leaves. The true stem is underground, but erect (Fig. 59).

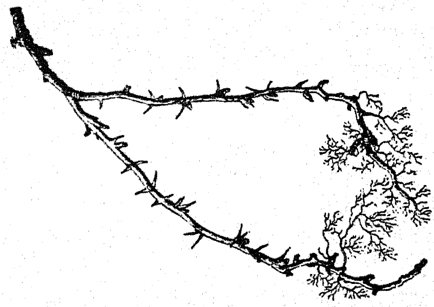


FIG. 57. STOLON OF GOOSEBERRY, GIVING OFF ADVENTITIOUS ROOTS.

Sometimes, stem branches are arrested in their growth in length. In place of the usual terminal bud at the end of the branch, the stem forms a sharp point called a **thorn**. This is very evident in the case of the hawthorn or may (*Cratægus Oxyacantha*), and it is easy to prove that the thorn is really a branch since it arises from a bud in the axil of a leaf, and sometimes the thorn itself is divided into one or two nodes and internodes towards its base, bearing foliage leaves at the nodes (Fig. 60). The sloe (*Prunus spinosa*) is another example.

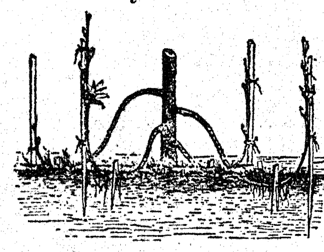


FIG. 58. VEGETATIVE PROPAGATION BY LAYERING. (*After Figuier.*)

Hooks differ from thorns in that, instead of being modified *complete* stems like the latter, they are formed by the modification of a *part* of the stem only, that is, the outer tissues. These hooks are used for climbing as in the case of the rose, especially the rambler rose and wild rose, blackberry (Fig. 61) and raspberry. Hooks may be found on any part of the stem, on the node, internodes and even on the petioles.

Stems may become flattened, as we have already seen in cacti. Sometimes they become so flattened and green that they are like leaves, and actually carry on the function of leaves, which is chiefly food manufacture. The butcher's broom (*Ruscus aculeatus*) is a case in point. There are several means of proving that these leaf-like structures are really stems. For example, rarely do real leaves produce buds and flowers on themselves.

FIG. 59. BANANA TREES IN CEYLON.
Note the very large leaves.

Yet on this structure, small buds will be seen half-way up the mid-rib, in the axil of a small scale leaf. Later these buds open out to form flowers. Also these flattened stems arise, as they should do, since they are branch stems, in the axil of the leaves, which here are reduced to small scales. Thus these structures, in spite of their leaf-like appearance and function, have the characteristics of stems. They are called cladodes (Fig. 62).

In favourable climates where luxuriant vegetation is found, such as those parts of the tropics where rain is plentiful, there is clearly a great struggle among the crowded plants to get plenty

of light and air. Trees are very favoured in this war of Nature, and millions of smaller plants are choked out during the course of a year. But some plants succeed, although they are not trees. They develop very long, thin trailing stems by means of which they scramble or climb up the larger plants, especially the trees. The ways in which they do this are manifold. For example, some twine round the stems of the support like a runner bean does (see Chap. XXII). Others climb by adventitious roots like the ivy, and others by hooks like the rose.

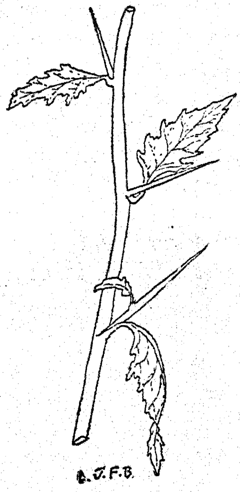


FIG. 60. TWIG OF THE HAWTHORN, SHOWING THORNS.

Some plants climb by means of **tendrils**. There are several kinds of tendrils, but some of these are modified stems, and are called **stem tendrils**. In plants like the white bryony (*Bryonia dioica*), the twining tendrils are modified branch, axillary stems (Fig. 63). Other stem tendrils, instead of twining, develop flat adhesive discs at their tips, by means of which they stick to their supports, as in the case of the Virginian creeper (*Parthenocissus tricuspidata*) (Fig. 64). In the grape vine (*Vitis vinifera*) the tendrils are modified inflorescences (Fig. 65).

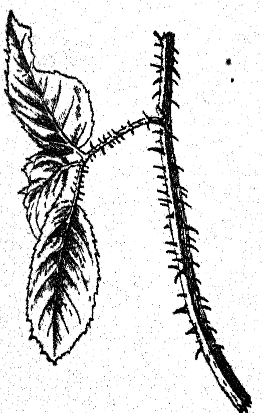


FIG. 61. TWIG OF THE BLACKBERRY, SHOWING HOOKS.

Modifications of the Leaf

Just like stems and roots, leaves sometimes become modified, and in so doing usually lose their normal function, which is chiefly that of food manufacture, and carry out the function for which they have become modified.

One familiar example is found in the **bulbs** of certain lilies, the bluebell (*Scilla nutans*), onion (*Allium cepa*), tulip (*Tulipa*) and lily (Fig. 66). The function of the bulb is similar to that of the tuber and corm. In the case of the bulb, however, the bulk of the fleshy part is not a swollen stem, but swollen, fleshy, colourless leaves. The best way to examine a bulb is to cut it vertically in half. We then see that it is really a shoot, which is composed

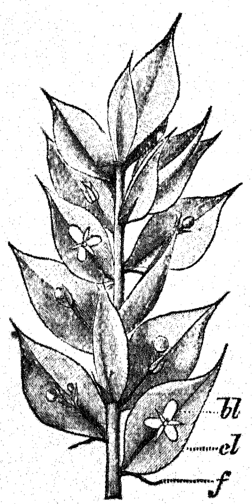


FIG. 62. TWIG OF THE BUTCHER'S BROOM. *cl*, cladode ; *f*, leaf ; *bl*, flower.
(*After Strasburger.*)

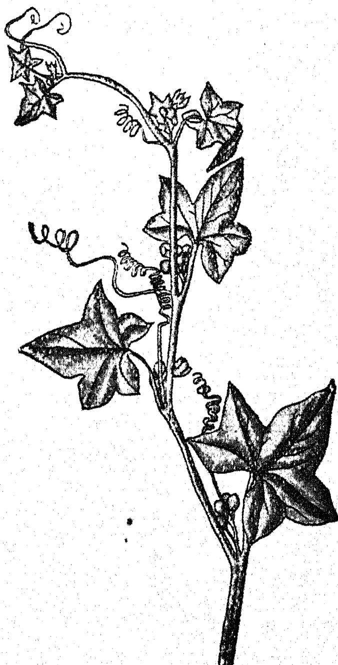


FIG. 63. BLACK BRYONY, SHOWING STEM TENDRILS PRODUCED IN THE AXILS OF THE LEAVES.
(*After Strasburger.*)

of stem, leaves and terminal bud (Fig. 51). The stem has become modified into a flat, bun-like structure which gives off adventitious roots round its edges. From the centre of the upper surface the terminal bud is given off, and finally grows out to produce the foliage leaves and the flowers. The lateral leaves are very thick and colourless and store the food, except the outer-

most ones, which are thin, brownish in colour and membranous, for protection. In the axils of some of the thick, modified leaves, axillary buds may be found, and these may grow out to form other foliage leaves. Sometimes they may be seen already partially developed and green in a cut bulb (Fig. 66).

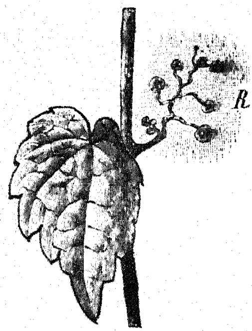


FIG. 64. VIRGINIAN CREEPER, SHOWING STEM TENDRILS WITH ADHESIVE DISCS.
(*After Noll.*)

Bulbs are another means of vegetative reproduction and perennation. The food reserve in the tulip is starch, and in the onion it is sugar.

It has already been seen that stems sometimes become modified to produce tendrils. Leaves may also become modified to produce **leaf tendrils**. In the common pea, the terminal leaflets only become so modified (Fig. 33). The lower leaflets remain unmodified to carry on the normal work, and the stipules become very enlarged to help in this work. In the yellow vetchling (*Lathyrus Aphaca*), the whole leaf is modified into a tendril, except the stipules which are enlarged and carry on the food manufacture (Fig. 67).

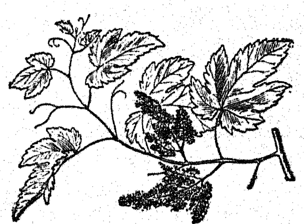


FIG. 65. A TWIG OF THE VINE, SHOWING HOW THE TENDRILS ARE MODIFIED INFLORESCENCES.
(*After Gilg.*)

Leaves are sometimes reduced to sharp **spines** in order to form a means of protection against animals. Only a part of the leaf may be so modified, as seen on the edges of the holly (*Ilex aquifolium*) and barberry (*Berberis*) leaves. It is almost certain that this modification serves for protection, for in most holly trees the modifications are very evident on the lower leaves which are within easy reach of animals, whereas the leaves higher up bear scarcely any spines (Fig. 68).

In some plants the whole leaf becomes modified into a spine

as in the case of the gorse (*Ulex europæa*) and cacti (p. 58). In the gorse other spines are produced also by branch stems, so that arguing logically we should find long spines arising from the axils of other spines; and this is exactly what we do find.

In the barberry it is possible to see all stages of modifications on the same plant, from a completely modified leaf to a leaf with

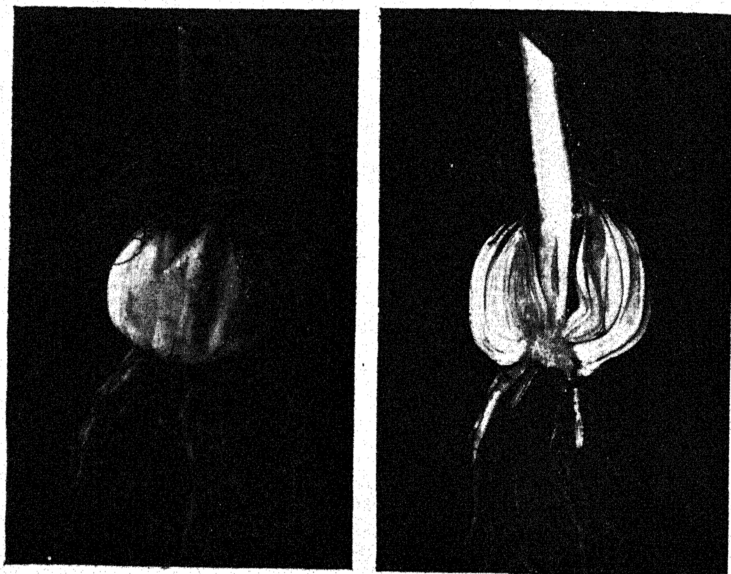


Fig. 66. Bulb of a Lily.

On the right is a longitudinal section showing the fleshy leaves; and a new bulb, in an axillary position, to the left of the base of the flowering shoot.

(*Photo. R. A. Malby.*)

a few spines on its edges. In the false acacia (*Robinia*) the spines are produced by modification of the stipules so that there are two spines given off at the base of the petiole (Fig. 69).

The Australian acacias and certain myrtles show an extraordinary kind of leaf modification. The lamina, which is normally compound, often completely disappears, and the petiole becomes flattened in order to carry out the normal work of the

leaf. The reason for this is not far to seek. It is harmful to expose leaves to excessive light and heat. Such plants run a grave risk of over-exposure in the open tropical regions where they grow. But this modification acts as a counterbalance, for, whereas the normal lamina is orientated horizontally thus, facing the sun, these flattened petioles lie in a vertical plane, thus exposing their edges directly to the sun. Direct contact with the sun's rays is thus prevented. Such flattened petioles are called phyllodes (Fig. 70). Sometimes the complete lamina does not disappear, and at the end of the petiole some true leaflets may be seen (Fig. 71).

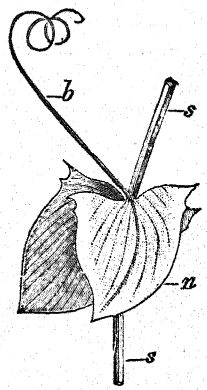


FIG. 67. LEAF TENDRIL OF THE YELLOW VETCHLING.

The whole leaf is modified, except the stipules which become enlarged. *b*, tendril; *n*, stipules; *s*, stem.

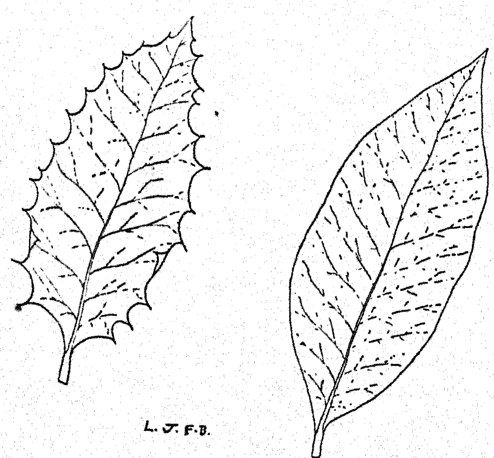


FIG. 68. LEAVES OF HOLLY.

On the left, a leaf from a low branch, showing spines; on the right, a leaf from a high branch, with no spines.

Some leaves become modified to protect the young undeveloped foliage leaves and flowers in a bud. They are called scale leaves and have already been examined, in the bud.

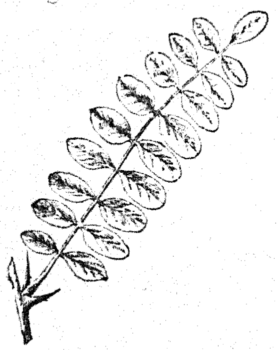


FIG. 69. COMPOUND LEAF OF *Robinia*, SHOWING THE TWO STIPULES MODIFIED TO FORM SPINES.

Until recently, flowers were looked upon as being modified shoots. As such, they appear where they would be expected, either at the end of the stem or in the axil of a leaf. As shoots they must bear leaves, and all these leaves are highly modified to form the various parts of the flower. Very often the flower is not subtended by a foliage leaf, but by a reduced tissue-like leaf which is called a **bract**. This is seen clearly in the *Iris*, daffodil, etc.

The buttercup flower is an excellent type for showing the various structures which may be modifications of the leaf (Fig. 239). In the centre of the flower may be seen a number of small pale-green structures called **carpels**. Surrounding these are many yellow, club-shaped outgrowths called **stamens**. Outside these again are several heart-shaped **petals**; and on the very outside are the pale-green, boat-shaped **sepals** (Chap. XVIII). It is easy to see the similarity of the flower, with all its leaf-like appendages, to a normal foliage shoot by cutting it through vertically. It will then be seen that the carpels, stamens, petals and sepals are all given off laterally from a flattened 'stem' which is called the **receptacle**.

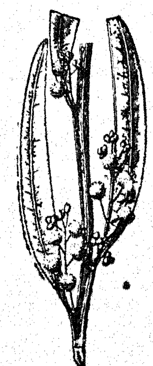


FIG. 70. PHYLLODES OF *Acacia marginata*.

Note the plane, with relation to the stem, in which they grow. In the axils, inflorescences are produced.

(*From Schimper's "Plant Geography."*)

Sometimes it is still further possible to show that all these floral

structures are related to foliage leaves, for it is possible to find all transitions from the normal foliage leaf to the various floral leaves, just as in the horse-chestnut bud it is possible to trace transitions from scale leaves to foliage leaves.

If a garden rose be examined, true stamens and true petals, and also some transitional members which are half petal and half

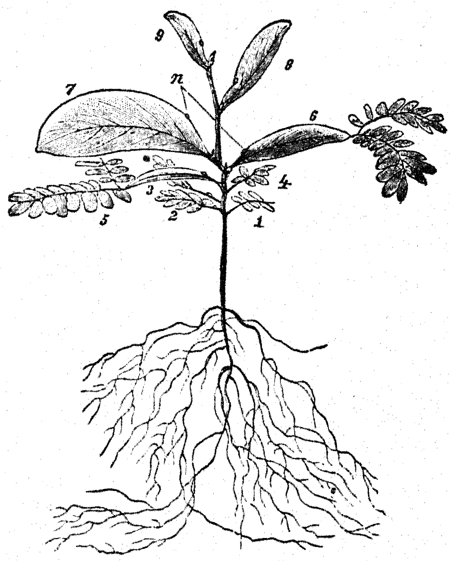


FIG. 71. SEEDLING OF *Acacia pycnantha.*

Note the horizontal position of the unmodified portions of leaves 1-6. In leaves 5 and 6, parts are modified as vertical phyllodes. 7-9 are completely modified as vertical phyllodes. *n*, nectaries on the phyllodes.

(*After Schenck.*)

stamen, may be found. Also some sepals may be partly green and boat-shaped, and partly coloured and petaloid.

In the tulip it is sometimes possible to see a transitionary type between the foliage leaf and the coloured floral leaf. It is usually seen in the case of a leaf growing on the flower stalk, near the actual flower. This leaf may be partly green and partly coloured (Fig. 72).

In 1790 the great German poet and philosopher, **Goethe**, who was also a botanist, published a book entitled "On the Metamorphosis of Plants." In it he made the statement for the first time in the history of botany that all the appendages of the stem are leaves, either foliage leaves or modified leaves. Thus, scales, bracts, and all the parts of the flower, sepals, petals, stamens, and carpels, are modified leaves. This conception held the field for many years with a certain amount of support, as we have already seen. To-day, however, botanists are beginning to suspect its truth, and it is quite likely that floral organs have no connexion with foliage leaves at all, in spite of the apparent relationship.

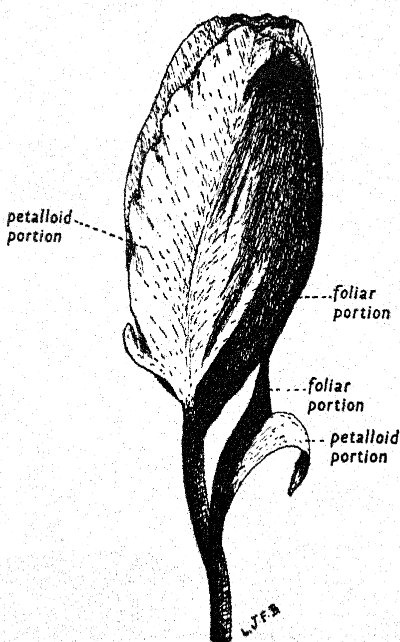


FIG. 72. TULIP FLOWER SHOWING A FLORAL LEAF PARTIALLY MODIFIED INTO A FOLIAGE LEAF, AND A FOLIAGE LEAF PARTIALLY MODIFIED INTO A FLORAL LEAF. The darker parts represent green, and the lighter parts pink.

Vegetative Reproduction in the Garden

Some of the plant modifications already considered are often used by the gardener, as we have already seen, for the artificial production of new plants. There are, however, others which are used in horticulture.

We have already seen that stems are capable of giving off adventitious roots. Now stems often do this from their cut ends, when they are severed, provided the cut end is given plenty of

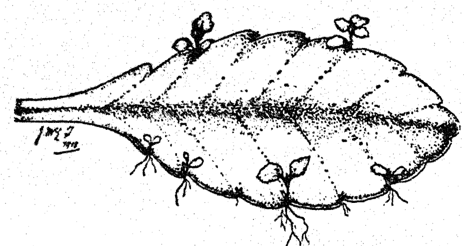


FIG. 73. LEAF OF *Bryophyllum* AFTER CULTIVATION ON DAMP SOIL, SHOWING ADVENTITIOUS PLANTS BEING PRODUCED IN THE NOTCHES OF THE LEAF.
(*After Thompson.*)

moisture. Some plants are more susceptible to such treatment than others, for example, the willow, which we have already considered. The geranium and carnation will do the same, and 'cuttings' are taken for this purpose.

Begonia and *Bryophyllum* illustrate a curious method adopted by horticulturalists for the production of new plants. It is somewhat similar to the method of cutting, but in this case the cut surface is that of the leaf and not the stem. If a *Begonia* leaf be cut either in the petiole or the lamina, the cut surfaces, if kept damp by, say, placing on a damp soil, will give off adventitious roots into the soil and adventitious shoots into the air (Figs. 73 and 74). In this way, new plants are produced and the old leaf finally dies away, once the young plant has made itself independent.

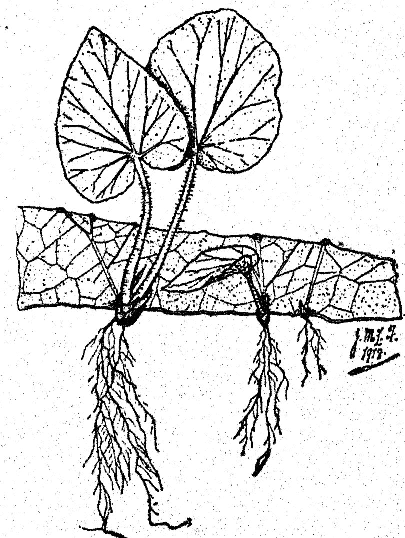


FIG. 74. PART OF A *Begonia* LEAF BEARING ADVENTITIOUS BUDS AFTER CULTIVATION, IN HEAT, ON A DAMP SOIL.
(*After Thompson.*)

This process is a much quicker method of producing new plants than by seeds.

Still more artificial methods of vegetative reproduction known to the gardener are the methods of **budding** and **grafting**; but these will be dealt with in Chap. IX in connexion with the consideration of trees.

PRACTICAL WORK

Wherever possible, one should collect material for study, personally, making a note of the features of the surrounding country, and especially the other types of plants with which the collected material is associated.

1. Examine and make a drawing of the root system of the lesser celandine. Note the fibrous, normal roots, and the club-shaped root tubers. Make a thorough examination, and write an account of those features which prove that these tubers are modified roots.

In a similar way, study the much larger specimens of root tubers in the *Dahlia*, if material is available.

2. Tear a spray of ivy from an old wall, or the trunk of a tree. Note how difficult it is to do this without breaking the stem of the ivy, thus showing how tenaciously the adventitious roots cling to their support. Examine and draw these adventitious, climbing roots, and state why they must be of adventitious origin.

3. Not all maize plants will show examples of stilt, or buttress, roots; but many do. In a field where maize is growing, make a thorough search for stilt roots, and draw such a plant without removing it from the soil. This gives a better conception of the function of such roots. Note how they are very like the flying buttresses on a building.

4. Carefully dig up a complete, small potato plant. Wash all the soil away from the subterranean portion, and then look for stem tubers. Note their position. Examine a tuber in detail, looking for the features already described, and state the reasons for distinguishing between this type of tuber and that of the *Dahlia* or lesser celandine. Make a drawing of the whole plant and also of one tuber enlarged to show details.

Keep a 'seed potato' stored in a dark cupboard over the winter. In the spring, examine it periodically, and note and record what happens. Several of the buds in the 'eyes' will shoot out. Note that the shoot is produced first. Later adventitious roots are formed near the base of the shoot. At the same time, the tuber begins to shrivel up. Why is this? Make a drawing of the sprouted tuber.

Gardeners, as has already been stated, very often divide a tuber into two or three parts for the sake of economy, before sowing.

This is quite safe, provided each portion has at least one 'eye'. But, to help matters still further, the cut surfaces are usually covered with lime, two or three days before sowing. Perform this operation, and note the effect on the cut surface. Why is this done ?

5. Examine the corm of a crocus or *Gladiolus*. Carefully remove the scale leaves and look for any small, white axillary buds which may be present. Look also for the old corm and any young ones. Make a drawing of the external features of the corm.

Cut a longitudinal section of a corm, and examine and draw the structure at the cut surface. Note the swollen stem, roots, terminal bud, etc. Correlate each part with the corresponding parts of a normal unmodified shoot, and describe in what ways the parts of the corm have become modified.

6. Make a similar examination and drawing of a typical bulb, such as that of the hyacinth, tulip, onion, etc. Compare and contrast the different structures of the bulb with those of the corm.

7. Try to uproot some couch-grass or sedge or some other plant which has a rhizome. Note how difficult it is, owing to the subterranean, creeping habit of the plant. Examine and draw a part of the rhizome in detail, noting especially the origin of the aerial, foliage leaves, and the roots. Note also the scale leaves.

8. Collect some specimens of creeping stems. There are several good examples which are common, such as moneywort (creeping Jenny), *Abronia*, ground ivy, etc. Note the long, recumbent habit of the stem, the absence of scale leaves (compare this with the rhizome), the position of the adventitious roots, etc. Make comparative drawings of the types collected.

9. Examine the structure of the strawberry plant. Either cultivated or wild strawberry will serve the purpose. Look for and draw examples of runners, and how they form new plants.

10. The houseleek is not a very common plant. It is sometimes found growing on very old walls, and, in some country districts, it may be found growing on the tiles of very old cottages, where it is actually cultivated in order to keep the tiles together. Try to obtain a specimen, and look for and draw examples of offsets.

11. Make a study of examples of stolons. Note the curved nature of the stems and how the adventitious roots are given off from that part of the stem which touches the ground. Note exactly where the new adventitious shoots are formed. The currant and gooseberry are good material for this purpose.

12. Collect some shoots of the hawthorn in early spring. Note the general character of the woody stem, and the leaves. Look for the thorns, and note especially their position on the stem by means of diagrams. Look also for larger examples, which, themselves, will be seen to be bearing foliage leaves. Explain why we know that these thorns are actually modified branch shoots.

13. Study the hooks on the stem and petioles of the bramble or rose. Compare them with thorns, and explain why the hooks cannot be modified branch shoots. Study carefully their shape, as compared with thorns, and explain this.

14. Examples of butcher's broom can usually be obtained from the florist or even from a garden, where it is sometimes cultivated to form a low hedge. Examine the cladodes carefully, especially with relation to the very reduced leaves. Fully explain why we know that these also are modified branches.

15. Study, draw and describe examples of stem tendrils. Good examples are: the twining tendrils of white bryony, the adhesive tendrils of the Virginian creeper, etc. Examine also the tendrils of the grape vine—it is best to examine this while the vine is in flower—and try and discover, by comparison, why we know that the tendrils are modified inflorescences.

14. Examine specimens of leaf tendrils. Note by their position and relation with other leaf structures why they are leaf modifications, and from this point of view make comparisons with the stem tendrils. Note the difference between the leaf tendril of the garden, or sweet, pea and that of the yellow vetching.

15. Make a comparative study of the leaves of a holly tree, choosing examples from the lower branches and the higher. Note the spiny nature of some of them. Show the different types by means of diagrams. Barberry, too, is a good example of a spiny leaf. This shrub is often cultivated in gardens and shrubberies. Look for various types of spiny leaves, on the same shrub, from the very spiny to the almost smooth (entire) margin.

16. *Robinia* is also a commonly cultivated plant. Try to obtain a branch of this plant, and examine and draw the leaves, noting the modification of the stipules.

17. The gradual transition of one floral organ into another, such as that of petal into stamen, offers splendid opportunity for the study of the relationship of the various floral parts.

One should be able to find all types in a garden, or even in cut flowers purchased from the florist. Good examples in which to look for this phenomenon are the cultivated rose, tulip, anemone and pæony. In the tulip, transition from foliage leaf to floral leaf is quite a common sight. In the rose, transitional types between sepal and petal, and petal and stamen, may very often be seen.

Field and Garden Work, Etc.

The study of various modifications of plant organs is a fascinating one, since it is possible to go on almost *ad infinitum* finding various interesting examples. This can be done in the field, the garden, greenhouse, botanical gardens and so forth.

It is not suggested that special excursions should be arranged for this purpose, but, whenever such excursions are arranged, one

should keep on the look-out for any type of modification. Whenever one is found, it should be examinéd and drawn. The function should be decided, and, most important of all, it should be discovered what organ has been modified to produce it.

In the garden, examples of suckers should be looked for, especially those of mint and plum.

If possible, an excursion to a nursery garden should be arranged. There, all types may be examined; and much profit could be obtained from a discussion with the gardener. Try to see examples of layering, and the production of strawberry plants from stolons. Make drawings, or take photographs in the garden.

A visit to a large greenhouse, or, better still, the houses of a botanical garden, would be well worth while in this connexion. There, one may see examples of the banana plant, cacti, tropical orchids with their aerial roots, *Acacia* plants with their phyllodes, etc. In some large nursery greenhouses, the vegetative reproduction of *Begonia* plants from leaves may be seen.

When making these visits, it is always advisable to make drawings or take photographs. It is also very valuable, and much more interesting, to approach the owner, gardener, or guide, tactfully and courteously, and try to get him to discuss the examples with you. More information can be gleaned this way than any amount of study from a book, or practical study without discussion.

CHAPTER V

INTERNAL ORGANISATION OF LIVING THINGS

Methods of Study

THE science of botany involves the study of everything in connexion with the plant kingdom. This includes a study of internal, as well as external, appearance, gross and detailed. The study of the form and structure of plants is called **plant morphology**. The study of the various functions which a plant performs is called **plant physiology**.

Then there is the study of the thousands of different plants, how they differ from, and how they resemble, each other, in order that they may be classified. This is called **systematic botany**. The geographical distribution of plants, too, is important, for it is common knowledge that plants which will grow in one geographical district, for example, the tropics, will not flourish in another. This study of plant distribution is called **plant geography**. Just as it is possible to divide the earth into certain geographical regions, so can the plants or **flora** and the animals or **fauna** be divided up into geographical groups.

But plants depend so much upon their surroundings that the study of this environment or **habitat** is necessary in order to understand the form or **habit** of the plant. In a study like this one cannot help but be impressed by how much a plant's structure or habit depends upon its habitat. Habitat can differ widely within a single geographical region. For example, such habitats as woods, meadows, bogs, ponds and streams, etc., can all exist in a small hilly district. Therefore plant geography is not enough. More details of the habitat such as the chemical and physical nature of the soil, light, moisture, effect of animals, etc., are required. This detailed study is called **ecology**.

Plants are living things like ourselves, and, like ourselves, they

are susceptible to disease. For example, in 1846 the whole potato crop in Ireland, upon which the people of Ireland depend so much, was attacked by a disease which had never been

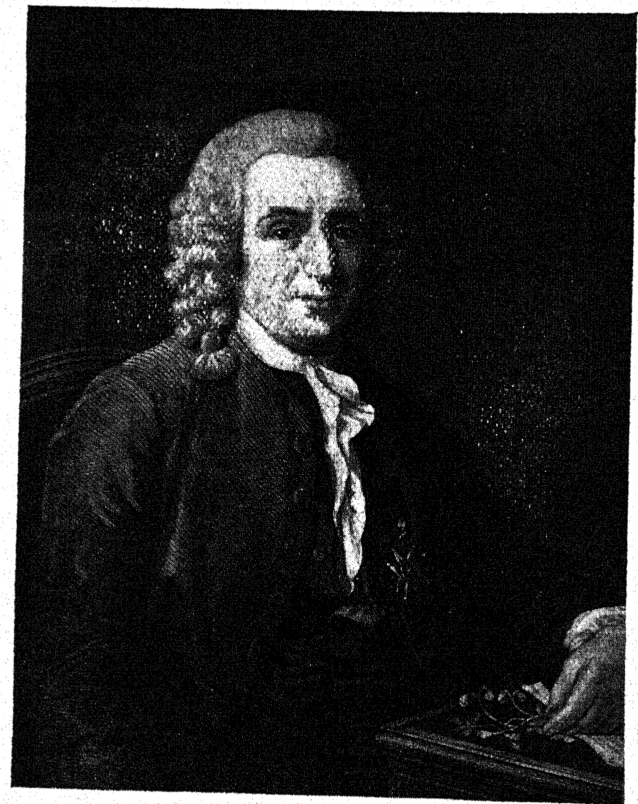


FIG. 75. CARL VON LINNÆUS, 1707-1778.
The Swedish botanist who laid the foundations of plant and animal classification.

noticed before 1840, called the potato blight. It did so much damage that a serious famine resulted. There are thousands of plant diseases, and their study is known as **plant pathology**.

Plant breeding, that is, the artificial attempts by the horticulturalist and the professional man of science at breeding better plants and plants which are more able to withstand certain conditions, is becoming an important branch of study. This branch of botany is called **plant genetics.**

It is possible to go still further into the various divisions of botanical science, but we will leave them until the occasion arises. Sufficient has already been said to show what a large number of subjects may be studied in botany and how important they are.

But botany, like the other sciences of physics, zoology, chemistry and geology, etc., is not now what it was. It has undergone great development, especially during the last century.

Divisions of Botany

Historically, botany dates back, not decades, but centuries. We have historical evidence that the Chaldeans, Egyptians and Greeks, who took science seriously, included botany as one of their subjects. **Theophrastus,** a friend of Aristotle, wrote fifteen books on various aspects of plants and their uses. Then the 'elder' **Pliny,** the Roman writer and philosopher, described many plants from the medicinal point of view. Studies of plants have also been traced back to the Arabians.

Following this, however, learning in Europe, including that of botany, made little progress until the sixteenth century when there was a revival, bringing with it an appreciation of the merits of botany. A physician named **Otto Brunfels,** who lived in Berne, in Switzerland, is supposed to have restored European botany in the sixteenth century. Following closely in his wake, **William Turner** began to lay the foundations of botany in Great Britain. In 1551 he published a book on the medicinal study of plants. But he merely classified plants according to their medicinal virtues and made no attempt to classify them so correctly as they are to-day, irrespective of their medicinal characteristics.

Plant classification was the next study that received attention. The first attempt, early in the sixteenth century, was made by **Cæsalpinus,** an Italian. In England, **John Ray** published a book

on plant classification in 1682. In 1669, **Robert Morison,** the first professor of botany in the University of Oxford, published a classification of plants.

FIG. 76. CHARLES ROBERT DARWIN, 1809-1882.

The English naturalist whose work on the origin of species and the evolution of plants and animals opened a new era of biological thought.

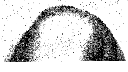
The classification of plants which we use to-day, based chiefly on the characteristics of the flowers, was founded in the middle of the eighteenth century by **Linnæus** (Fig. 75). But the system has now been very much modified (see Chap.

XXIV). It is an even more natural classification than that of Linnæus, and that is due very much to the changes made by the British botanist, **Robert Brown,** and still more so to the great naturalist, **Charles Darwin** (Fig. 76), who was born at Shrewsbury in 1809.

Darwin did a great deal of his work in geology, zoology and botany when he went as naturalist on the *Beagle*, a surveying ship which sailed to many parts of the world, completely circumnavigating it for the sake of discovery. Much of his writing afterwards was done at the village of Downe, in Kent, where he died in 1882. Downe House, the house where Darwin worked, has now been presented to the British Association for the Advancement of Science and has been opened to the public as a museum (see also Chap. XXIV).

Early studies of plants were chiefly from the point of view of their use in medicine. The study of the internal structure of plants or **plant anatomy** may be said to have begun with the Englishman, **Nehemiah Grew,** and **Marcello Malpighi,** an Italian, who published their discoveries between 1770 and 1790. It is common knowledge now that one of the most necessary pieces of equipment to nearly every scientific worker is the **microscope,** both simple and compound. Before the invention of this instrument, comparatively little was known of the internal structure of the plant. This internal anatomy began with the studies of Grew and Malpighi, although the latter worked chiefly with animals. This study of internal plant anatomy fell into the shadows afterwards; but in the middle of the nineteenth century it was brought out into the limelight again by **Hugo von Mohl.**

We owe much of our present-day knowledge of the morphology of plants, especially the detailed internal structure, to two German botanists, whose names will go down in the annals of science as being two of the most important founders of the detailed study of plant structure. One was **Professor Wilhelm Hofmeister**; the other was **Professor Karl Ritter von Goebel.** Two British botanists, who have been responsible for the study of plant structure, are **Professor F. O. Bower** and the late **Dr. D. H. Scott.**



Our knowledge of plant geography has accumulated chiefly from expeditions made on land and water for many centuries. Great men of the past such as **Charles Darwin**, **Sir Joseph Hooker**

FIG. 77. SIR JOSEPH HOOKER, 1817-1911.

The English botanist, formerly a director of the Royal Botanic Gardens, Kew, who made an extensive study of plants in many parts of the world.

(Fig. 77) and **Dr. Alfred Russel Wallace** (see Chap. XXIV) did much towards the establishment of this subject.

Fossil plants shed a great deal of light on the flora of past ages. Many British botanists have added greatly to our knowledge of the past floras by studying fossils obtained from rocks of various

strata. Among them were **Dr. R. Kidston, Professor W. C. Williamson**, and **Dr. D. H. Scott.** Botanists of to-day working in this field include **Professor W. H. Lang** and **Professor A. C. Seward** (see Chap. XXIV).

Plant pathology is a much more recent study; but it is now one of the most important, from the economic point of view. To-day we have plant pathologists in universities, research institutes and under Governments throughout the whole civilised world. This branch of botany began chiefly with the works of **Anton de Bary**, the French botanist, who worked towards the end of last century, and much was done towards its furtherance by the Englishman, **Professor Marshall Ward.**

Plant genetics too is profoundly important, and began with the efforts of **Gregor Johann Mendel** (Fig. 340), an Augustinian monk of Brünn, Austria, whose work, however, was neglected at the time. **Professor William Bateson** and **Professor Hugo de Vries** (Fig. 339) have added much to our knowledge of this subject (see Chap. XXIV).

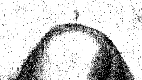
Plant physiology, although an important branch, is a comparatively young one, yet, as we shall see in later chapters, it had its investigators centuries ago.

Protoplasm

A question of fundamental importance is: What is the basis of life? What makes a plant or animal live?

Life is due fundamentally to the presence in all living things of a substance called **protoplasm.** Protoplasm is the essential substance in all living things; nevertheless, few living things are composed solely of protoplasm. Many other non-living constituents are found, such as wood; but these substances are all produced in a mysterious fashion primarily by the protoplasm. *Thus all living things may be said to be composed of protoplasm and its products.*

Protoplasm is not a rigid solid, and therefore cannot exist in large bulky masses. It usually exists as microscopically small units, and each unit surrounds itself by a more rigid membrane for support. This rigid support is common in plants, but not so common in animals.



The units of living protoplasm are called **cells**, and the supporting box-like membranes which are dead are called **cell-walls.** Here lies the basis of the study of plant anatomy. It was due to the discovery of cell-walls first of all that cells themselves were recognised, for the walls are much more easily visible than the cells. **Robert Hooke,** the English microscopist, was the first to discover cell-walls, in 1667. It was he who gave the name 'cell', for the little compartments which he could see in the bottle cork which he was examining had the appearance of the cells of a honey-comb (Fig. 78). But he did not recognise the real colourless cells of living protoplasm enclosed by those honey-comb-like dead cell-walls. That was left to Malpighi and Grew. Yet although these two discovered the real cells, the great importance of this discovery was not recognised until two hundred years afterwards.

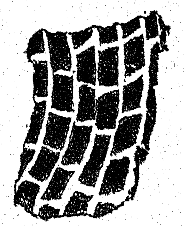


FIG. 78. COPY OF A PART OF HOOKE'S ILLUSTRATION OF BOTTLE CORK, WHICH HE DESCRIBED AS "SCHEMATISM OR TEXTURE OF CORK."

Protoplasm, under the microscope, appears to be a clear viscous fluid which is capable of changing its shape under certain circumstances. It behaves normally like a liquid because (*a*) if drops of water are enclosed in it they take up a spherical form ; (*b*) very small particles when embedded in it do not remain stationary, but vibrate quickly—this vibration is called **Brownian movement** after Robert Brown, who first discovered it in 1827 ; (*c*) if subjected to an electric shock, a particle of protoplasm takes up a spherical shape.

As will be seen later, protoplasm is composed of many different chemical substances, but before doing this the condition in which these substances are present is worthy of study. Water is present in the protoplasm, so that the rest could conceivably be present dissolved in it. Actually some of them are, but others are not. This, therefore, brings us to a consideration of the nature of solutions.

It is well known that some substances will freely dissolve in water. The substance dissolved is called the **solute,** whereas the water is called the **solvent.** In a true solution like this, the

molecules of the solute are completely distributed in the solvent, so that *no two molecules of the solute are touching each other*. Most substances which will enter into true solution like this are called **crystalloids.**

There are, on the other hand, some substances which do not truly dissolve, although they appear to do so. They are not in true solution, for their molecules, instead of being quite separate, *are present in groups or aggregates*. Starch is of this nature. Such substances, in contradistinction to crystalloids, are called **colloids.**

The chemical substances which make up protoplasm are present in both conditions; some as crystalloids, and others as colloids. Therefore protoplasm may be looked upon as being a *crystallo-colloid.*

A table jelly is a colloid, and anyone who has seen a table jelly being made will therefore know that colloids can exist in several conditions. The jelly, when it is purchased, is very stiff and viscous. Then it is cut up and placed in hot water, when it becomes so fluid that it can be poured. Finally it sets, when it becomes more viscous, but not so viscous as in the first place. Colloids therefore exist in various degrees of viscosity. So can protoplasm.

A very viscous colloid is called a **gel**, and a very fluid colloid is called a **sol.** Sometimes, the condition can be changed, one into the other. Such changes are sometimes reversible and sometimes irreversible. An example of the latter is the 'white' of an egg. In its natural state it is a colourless sol. When it is heated it is transformed into a white, opaque gel, and cannot be reconverted into a sol again. Protoplasm is a reversible colloid, that is, it can be converted from the sol to the gel, or *vice versa*. Physically, therefore, protoplasm varies considerably, chiefly with regard to its colloidal condition.

Chemically, protoplasm varies extensively too. It is not just one chemical substance, but a mixture of many.

Water is the chief constituent of protoplasm. This varies from as much as 98 per cent. to so little as 10 per cent. The first reliable chemical analysis of protoplasm was made in 1881 by **Reinke and Rodewald.** Next to water come **proteins.** Once all the water

is driven off, proteins vary in percentage, from 40 per cent. in some plant protoplasms to 65 per cent. in others. **Carbohydrates** are present to the extent of about 12·5 per cent. dry weight, **fats** 12·5 per cent. dry weight, 6·5 per cent. **inorganic mineral salts** such as potassium nitrate, and the rest is made up of other substances which vary considerably in different cells. The nature of carbohydrates, proteins and fats will be considered in Chap. VI.

The many physical and chemical processes, which are responsible for the living activities of protoplasm, take place at the surfaces between the colloidal particles and the solution in which these particles are embedded. Considering the millions of surfaces that exist, even in a microscopic amount of protoplasm, there must be ample opportunity afforded for these chemical and other reactions. A very picturesque illustration of the nature of protoplasm in this respect was given in 1932 by the late **Sir J. Arthur Thomson.** Speaking of protoplasm he said that it "may be compared to an archipelago with a very large number of small islands on whose multitudinous coastlines there are endless opportunities for brisk trading". The "islands" are the colloidal particles, the sea is the solution containing dissolved crystalloids in which the colloidal particles are embedded, and the "brisk trading" is the thousands of chemical and other reactions taking place.

Such, then, is a rough idea of the physiological make-up of the cell, and it is thus clear that the protoplasm varies very much in chemical and physical constitution.

The Cell

The chief constituent of the cell is the protoplasm. This is almost invariably divided into two main portions. The bulk of it is made up of a colourless liquid, in the sol state, containing many granules embedded in it. This part of the protoplasm is called the **cytoplasm.**

Embedded in this cytoplasm is the other portion of the protoplasm, which is called the **nucleus.** It is ovoid in shape and is situated either near the centre of the cell or close to the edge. But wherever it is, it is never on the *outside* of the cytoplasm. In

other words, the nucleus is always completely surrounded by cytoplasm. The nucleus, like the cytoplasm, is composed of protoplasm, but the protoplasm of the two portions varies considerably, both chemically and physically. The nucleus varies chemically from the cytoplasm in that the former contains more phosphorus, and physically in that it is more of a gel.

All living cells contain cytoplasm, and by far the majority contain a nucleus. In the case of very young cells, this is all that they do contain. But nearly all plant cells are surrounded by the cell-wall which is composed of a carbohydrate called **cellulose** (Figs. 79 and 80).

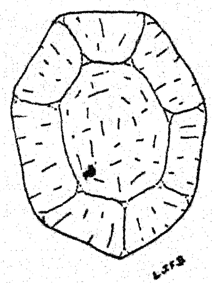


FIG. 79. A SINGLE YOUNG PLANT CELL (× ABOUT 1200).

When the cell begins to grow in size, the cell-wall begins to expand. However, the cell which it contains does not grow at a corresponding rate, since very little new protoplasm is manufactured by a growing cell. Therefore as the cell-wall expands, spaces will be formed inside it. The cytoplasm in a young cell is always pressed tightly against the cell-wall, and this always holds good, even for the older cells. Therefore such spaces as are formed during the cell's growth appear in the cytoplasm itself, and not between it and the cell-wall. Some cytoplasm invariably lines the cell-wall.

The spaces formed within the cytoplasm during growth are called **vacuoles**, but they are not empty. They contain water, with certain crystalloids dissolved in it. This solution in the vacuole is called **cell-sap**. The substances dissolved in the cell-sap varies. In the cells of the onion bulb and the beet, as we should expect, it is chiefly sugar. In the cells of the bean and pea seeds it is potassium nitrate.

Since the nucleus is always surrounded by some cytoplasm, it never abuts directly on a vacuole. In the case of a vacuolated cell, the nucleus may be embedded in the cytoplasm lining the cell-wall or it may be surrounded by a layer of cytoplasm and suspended within a vacuole, by means of fine threads of cytoplasm stretching from the cytoplasm surrounding the nucleus

and the cytoplasm lining the cell-wall. These suspending cytoplasmic threads are called **bridles.**

Nearly all cells are so small that they can only be seen under a microscope. Yet they vary considerably in size and form. For example, the cells of some bacteria are spherical and about 0·001 mm. in diameter (Fig. 7), whereas the cells of some fleshy fruits are 1 mm. in diameter. Cells may be spherical, cubical, cylindrical, polyhedral or prismatic in shape. The cells which form the fibres of some plants are long and tapering and may reach a length of 20 cm.

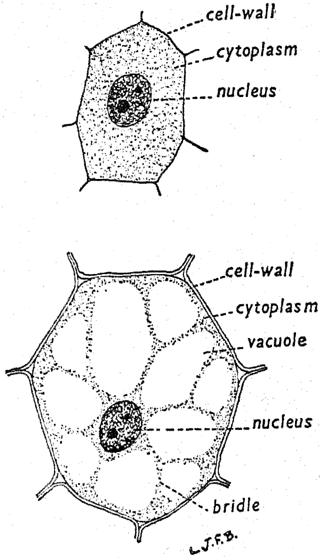


FIG. 80. SECTIONS OF TWO PLANT CELLS.

Above, a young cell; below, an older cell, showing increase in volume and the development of vacuoles (× about 800).

Division of Labour in the Plant

Many plants are composed of hundreds of cells, all joined to each other by their cell-walls. In some big plants, such as trees, there are millions of them. Such plants are said to be **multicellular.** On the other hand, there are plants which are each composed of one cell only—for example, bacteria (Fig. 7) and *Chlamydomonas* (Fig. 1). Such plants are said to be **unicellular.**

The cells of a multicellular plant can be compared with human beings. If you were living alone, absolutely cut off from contact with any other human being, you would have to do everything for yourself. A unicellular plant is like that. It performs all the processes of life within itself.

Now within a community of people, such as a nation like the British, we never find people who do everything for themselves. They split themselves up into groups, and each group does one

or perhaps several certain kinds of work only. Some grow food, like the farmers. Others manufacture it, like the bakers; others make our clothes, and others help to keep us healthy when we are well and to recover when we are ill; and so forth. This splitting up of all necessary work and allocating it to different people or groups of people is called *division of labour.*

In this respect the plant represents the nation, and each cell represents one human being within the nation. Human beings become modified to do their special work; bakers become skilful in kneading the dough; farmers become proficient in tilling the soil, sowing and reaping; clerks in adding up figures; doctors in treating the sick, and so on. So do cells become modified in order to carry out their special work successfully, as we shall see.

Tissues

Division of labour has another important characteristic. Men having the same kind of work to do often group themselves together. Coal miners, for example, congregate around the coal mines, and farmers relegate themselves to the land. Thus, within a community of people, so far as is possible, we have a segregation according to work (or function). So also do many cells which have the same kind of work to perform congregate into groups. Such groups of cells, having the same modifications of structure and therefore the same functions to perform, are called **tissues.**

The young cell is composed of nucleus, cytoplasm and cell-wall. Then it grows in size and vacuoles appear in the cytoplasm. These unmodified cells when collected together form a tissue which is called **parenchyma.** Food-storage tissue is usually composed of parenchymatous cells such as those in the beetroot and the potato tuber, and the fleshy parts of the fruit of the apple.

Living Tissues

When they become modified some cells still remain living, whereas others are killed.

In all the more advanced plants there must be some means of transporting food, for although all living cells must have food

only a few can manufacture it, and the latter are usually situated in the leaf. For food transport, special cells are used. Food is never transported in the solid state, but in true solution in water. The cells used for this purpose are originally parenchymatous. Then, as they grow, they become elongated, and all are superimposed on each other, giving a long chain of tubes, stretching from the leaves, down through the stems, to the roots. Since, however, such a chain is composed of many cells joined end on end, there are bound to be cross walls in the tube, wherever two such cells join.

These cross cell-walls, however, do not form an absolute blockade to the passage of dissolved water and food, for the solution can pass through cellulose. In spite of this, however, these walls would *impede* such progress. This is prevented by the cross walls becoming perforated by a large number of small holes, so that each wall looks like a sieve. Each cross wall is therefore called a **sieve plate,** and the whole tubular cell is called a **sieve tube** (Fig. 81). Throughout all this development the protoplasm persists, and finally remains as a thin lining to the sieve tube, yet, strange to say, the nucleus disappears.

Sieve tubes are found in all the larger plants, such as ferns, pines and flowering plants, grouped together with other kinds of cells, especially parenchyma, in the tissue known as **phloem**. In the flowering plants only, however, closely related to each sieve tube is another modified cell. It lies close to the tube and is elongated just as much, though in cross section it is not so large. It contains no vacuoles, but is full of cytoplasm and a well-developed nucleus. Since it always accompanies the sieve tube, it is called a **companion cell,** but its function is at present unknown.

Many plants grow in very dry regions, such as deserts and semi-deserts. Such plants are forced to take advantage of what little rain there is, collect more than it requires at the moment, and store the excess. For such storage of water, ordinary parenchymatous cells are used, but they become modified in that they grow to a tremendous size in order that their vacuoles can be very large and store the water. Such a tissue of cells is called **water-storage tissue** (Fig. 82).

Dead Tissues

Dead cell tissues are frequently used in the skeletal parts of the plant; they are also used for conducting water from

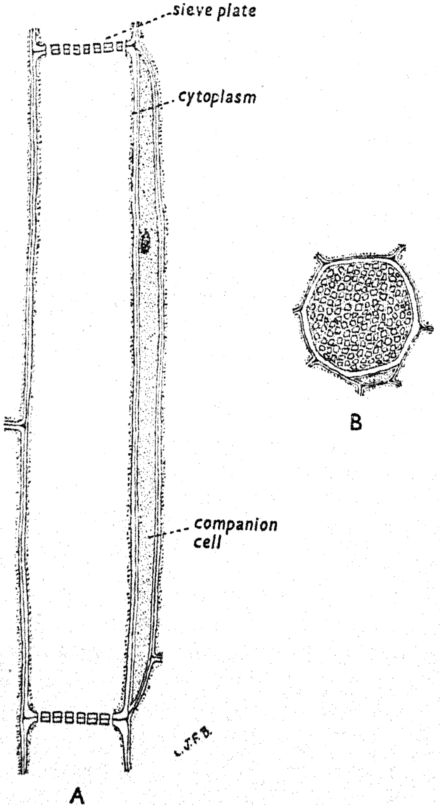


FIG. 81. A SIEVE TUBE.
A, in longitudinal section; *B*, in transverse section, passing just above a sieve plate (× 360).

one part of the plant to another, for such transportation must be at a much quicker rate than the transportation of food-stuffs.

All such cells must be strong, and in order to make them so *the cell-walls become thickened*. This is done by the formation of a substance called **lignin** or wood, on the cell-wall. This formation takes place at the expense of the protoplasm, which gradually disappears, thus causing the death of the cell. There are several forms of lignified cells, and their variety depends on the manner in which the lignin is deposited on the wall.

One type is that where the lignin is deposited almost completely over the whole surface of the cell-wall. The tissue formed of such cells is called **sclerenchyma**. There are two main types of sclerenchymatous cells, **stone cells** and **fibres**.

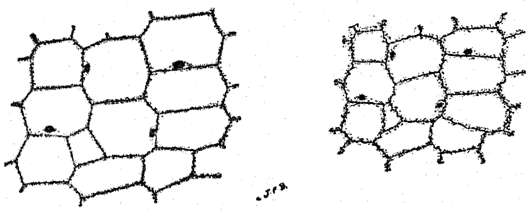


FIG. 82. WATER-STORAGE TISSUE.

On the left, tissue containing stored water; on the right, the same tissue reduced in volume after some of its water has been removed for the use of the plant (× about 170).

Stone cells scarcely ever form real tissues since they usually exist separately or in groups of just a few, and are usually embedded in a matrix of parenchymatous tissue. The stone cell is usually isodiametric in shape—that is, more or less spherical, though somewhat pushed out of shape by the close proximity of other cells. It is heavily thickened by the deposition of lignin on the wall, so that the **lumen**—that is, the space left by the cell which has disappeared—is reduced to practically nothing. At certain spots on the surface of the cell-wall, however, no lignin is deposited. As the deposit gets thicker and thicker, these unthickened spots form **pits** in the layer of lignin.

Wherever a pit is formed in one cell, another is formed in the stone cell adjoining it. Therefore, there is a communicating channel between the two stone cells; but the channel is not complete, for the original cell-wall still exists across it. The

original cell-wall, which persists and remains embedded in the middle of any thickened cell-wall, is known as the **middle lamella.** However, despite this continuation of the middle lamella across the pits, such pits greatly facilitate the passage of water and dissolved substances from one stone cell to another. Some pits are branched. These stone cells are not very common in plants; but they exist in great quantities embedded in the parenchymatous tissue of the flesh of the pear fruit. Their woody nature gives this fruit its gritty nature (Fig. 83).

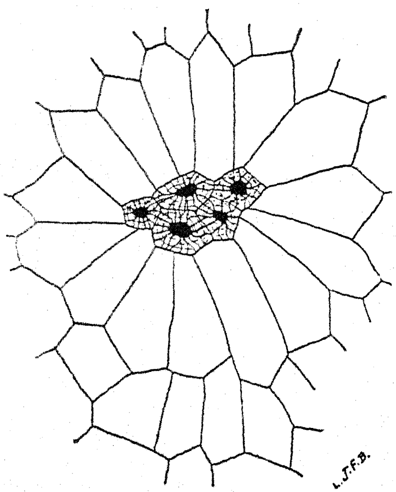


FIG. 83. A GROUP OF STONE CELLS EMBEDDED IN THE PARENCHYMATOUS TISSUE OF THE PEAR FRUIT.

The other type of sclerenchymatous cell is fibrous in nature and is therefore called a **fibre.** It resembles a stone cell in all features except that, instead of being isodiametric, it is very elongated, like a needle (Fig. 84). Sometimes the thickening in fibres is so great that the lumina are completely blocked up. Tissues made up of fibres are extremely hard, tensile and very elastic. Their strength is often as great as that of wrought iron and their elasticity even greater. The mechanical advantages of such tissues, especially to the stem, can well be realised. Fibres are very common in the woody tissues of the stems and roots.

Another important function of wood, besides that of mechanical strength through its fibres, is that of conducting water throughout the plant. Wood is therefore found in roots, stems and leaves; for water passes from the soil into the roots, up through the stems and into the leaves.

The fibres of the wood with small lumina or even no lumina at

all are clearly of no use for this function, so other dead cell modifications are used.

In a town the water supply is conveyed through pipes, which begin as large aqueducts from the reservoirs and then give off smaller and smaller branches until they reach us as the familiar small water pipes in our houses. The water system in the plant is very similar to this.

The water-conducting elements are long pipes. These elements all begin their development as living parenchymatous cells. Then they elongate into cylindrical, pipe-like shapes. But this is not enough. These pipes must be prevented from collapsing, for if they do collapse they will be useless for conducting purposes. Collapsing is prevented through the thickening of the wall by the deposition of lignin on it. But the lignin is never deposited all over the wall.

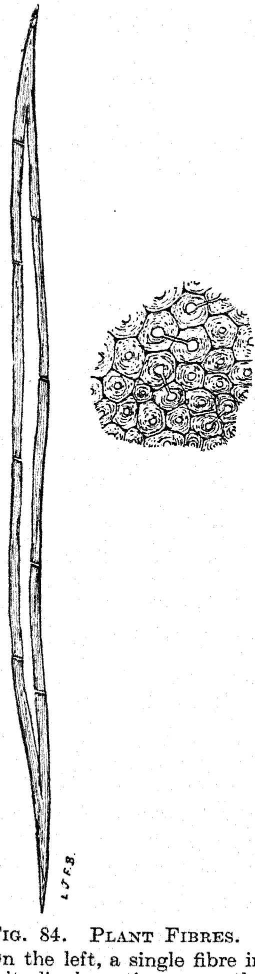


FIG. 84. PLANT FIBRES.
On the left, a single fibre in longitudinal section; on the right, a group of fibres (sclerenchyma) in transverse section. Note the pits (×220).

Certain water-conducting elements are called **tracheids**. The simplest type of tracheid is that in which the deposition of wood takes the form of parallel rings of lignin, deposited on the inside of the cell-wall at the expense of the protoplasm, which disappears. This tracheid is called **annular**. The next is formed by the deposition of wood in a spiral form, and such a tracheid is called **spiral**. In the next form, the wood is deposited all over the

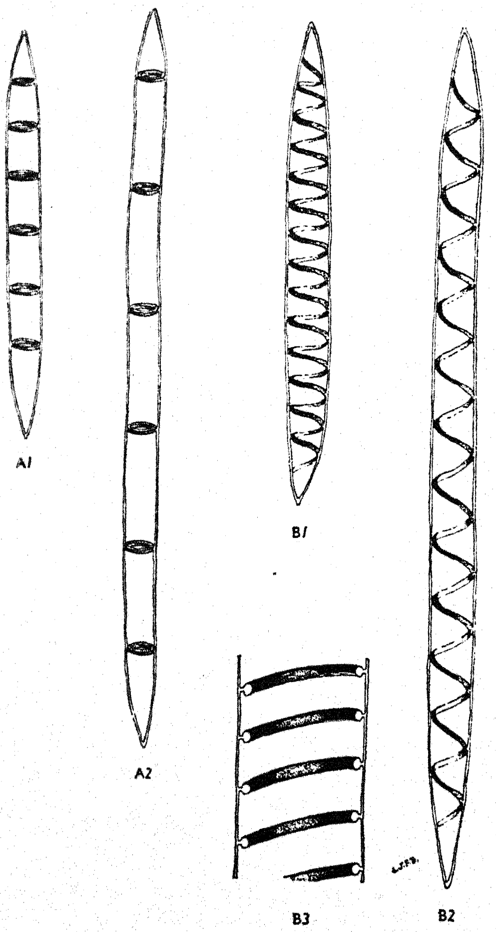


FIG. 85. ANNULAR AND SPIRAL TRACHEIDS.

A1, annular; B1, spiral; A2 and B2, the corresponding tracheids elongated by growth; B3, part of a longitudinal section through a spiral tracheid showing how the wood is deposited (× 300).

cell-wall except that unthickened parts are left in parallel lines, giving a ladder-like or scalariform effect. These are

scalariform tracheids. The last form is similar except that the unthickened portions are left in a form of reticulum or network, thus forming the **reticulate** tracheid (Figs. 85 and 86).

Since water conduction is an immediate necessity, even to a very young plant, such elements are formed in those parts of the root and stem which are still growing in length and, later on, those which are not growing in length. The tracheids themselves, once formed, cannot elongate as they are dead; but since cellulose is elastic and lignin is not, the unthickened portions of

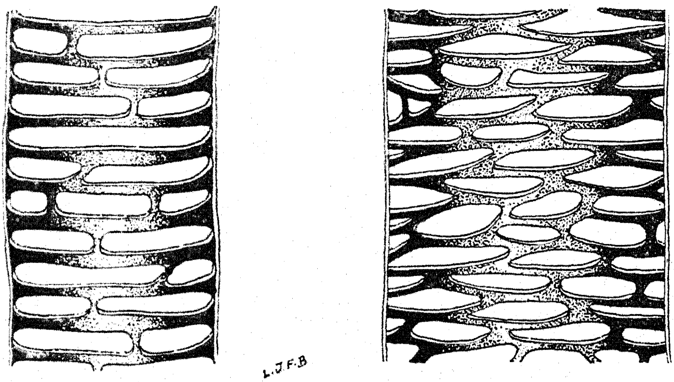


FIG. 86. SCALARIFORM TRACHEID (LEFT) AND RETICULATE TRACHEID (RIGHT) ($\times 200$).

the tracheids can be stretched. This is possible, as may well be imagined, in the case of the annular and spiral tracheids, for in the former, the annular thickenings would merely be pulled farther apart, and in the latter, the spiral could be pulled out like a spring; but not in the other two cases. Therefore in the young growing parts, the wood is formed of annular and spiral tracheids, whereas in the older non-growing parts, the scalariform and reticulate tracheids appear.

Tracheids, like sieve tubes, are superimposed on each other, forming chains of conducting elements. However, in this arrangement, there must be cross walls where the tracheids meet, and these will impede the progress of the passage of water. There are, however, certain other conducting elements, which, in

this respect, are even more efficient. They are very similar to the four types of tracheids, but differ in that the cross walls disappear during their formation. These are called **vessels**, and form admirable conducting channels for water. However, apart from this added facility, vessels are like tracheids. There are annular, spiral, scalariform and reticulate vessels, and they differ from tracheids only in that whereas tracheids are each formed from one cell, vessels are formed from several.

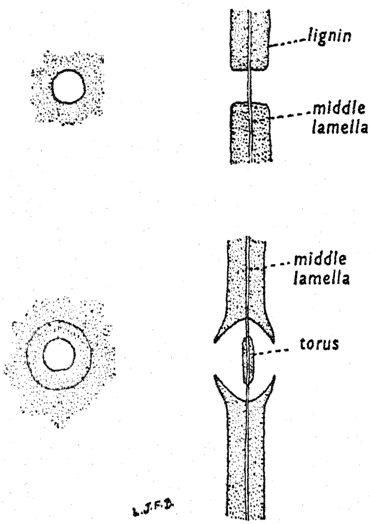


FIG. 87. ABOVE, SIMPLE PIT IN SURFACE VIEW (LEFT) AND LONGITUDINAL SECTION (RIGHT); BELOW, A BORDERED PIT IN SURFACE VIEW AND LONGITUDINAL SECTION (× 375).

In some cases, the vessel is thickened to a high degree, and the regions which remain unthickened are comparatively small in size though large in number. They are circular and are therefore pits; but they differ considerably in structure from the simple pits already considered. A glance at Fig. 87 will show that a simple pit in surface view takes the form of a circle, whereas that of the pit in question is bordered by another circle. Hence such a pit is called a **bordered pit.** When viewed in section, the simple pit is of a cylindrical shape, with the middle lamella passing across it. In the case of the bordered pit, however, on each side of the middle lamella there is a dome formed by the thickening of lignin. The top of each dome is, of course, perforated, else there would be no real pit. Fig. 87 shows how this structure appears to be bordered in surface view; for lignin, under the microscope, is rather transparent; so the actual perforation of the dome appears as one circle and the base of the dome

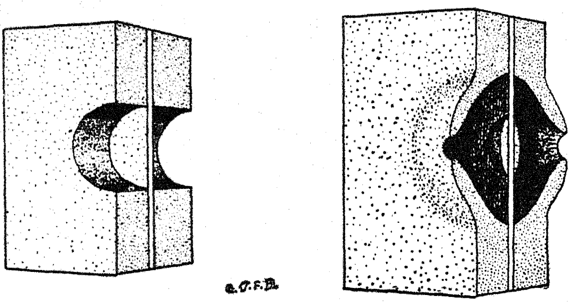


FIG. 88. DIAGRAMMATIC REPRESENTATIONS OF A SIMPLE PIT (LEFT) AND A BORDERED PIT (RIGHT) IN LONGITUDINAL SECTION.

Note the middle lamella passing across the pit in each case; in the bordered pit the torus is formed by the deposition of more wood on part of the lamella passing across the pit.

at the middle lamella appears as another circle, surrounding the first in a concentric position. A portion of the middle lamella, actually crossing the bordered pit, also becomes thickened by lignin to form a disc-shaped structure called the **torus**. Fig. 88 perhaps gives a better idea of the structure of simple and bordered pits. Vessels in the older parts of wood are usually covered with bordered pits, as shown in Fig. 89.

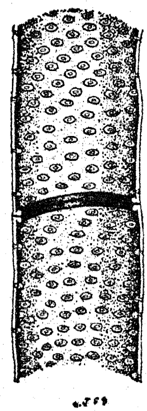


FIG. 89. PART OF A WOOD VESSEL SHOWING THE REGION WHERE THE CROSS WALL HAS DISINTEGRATED.

Note the large number of bordered pits.

PRACTICAL WORK

SIMPLE AND COMPOUND MICROSCOPES

Whereas the compound microscope is not necessary for a great deal of the work involved in the study of plants, especially for beginners, the **simple microscope** (commonly called a 'lens') is practically indispensable. One should never go into the botanical laboratory or the field without a simple microscope. A folding type is the best, since it gives two or three lenses of different magnifying powers (Fig. 90). Though such a lens reveals little more than can be seen with the naked eye, it is invaluable in magnifying such structures, thus not only

preventing eye strain but also bringing details clearly to the notice of the observer. Where magnifications of not more than 20 diameters are required, a simple microscope will do.

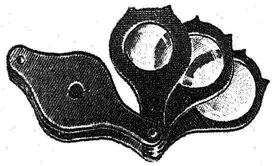


FIG. 90. A TRIPLE POCKET MAGNIFIER. THREE LENSES OF DIFFERENT MAGNIFYING POWER.

On the other hand, when one comes to the study of the internal structure of the plant, and to examine cellular structure, a compound microscope is necessary, since much higher magnifications are required.

The structure of a compound microscope is seen in Fig. 91. The important parts of the instrument are extremely delicate, and it should therefore be treated with the utmost care. The image of the object is obtained by the objective, and this image is then magnified by the eyepiece. Both these parts contain lenses. The coarse adjustment is used for raising and lowering the tube of the microscope, thus getting the image into focus. For more exact focusing, the fine adjustment is used. When, however, the object has been mounted on the stage, it should be got into the field of the microscope by gently moving it about; then it should invariably be focused by the coarse adjustment. The fine adjustment can be used finally, though the latter is scarcely ever necessary except during the course of high-power work. Two objectives are usually enough; one to magnify about 50 diameters and another to magnify 300 to 400 diameters.

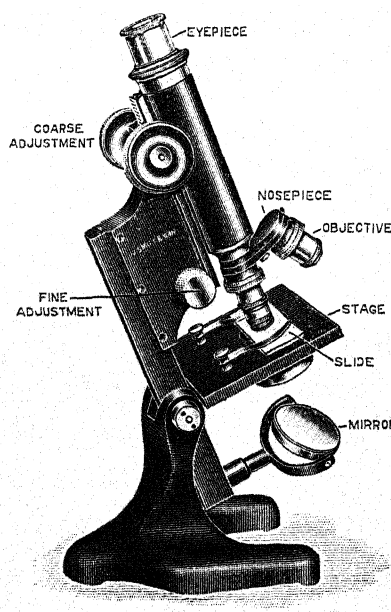


FIG. 91. A TYPICAL COMPOUND MICROSCOPE.

In the course of all normal microscopic work, it is necessary that the object should be more or less transparent, for the light must pass through it. The light is directed up through the object on the stage by means of the mirror, the plane of which is adjustable. It is always best to work

with daylight. A good light is necessary, but direct sunlight should be avoided. Artificial light is not desirable, unless it is possible to use 'daylight' electric bulbs.

Many objects to be examined under the microscope are already sufficiently small and transparent to be placed on the stage complete; but in other cases, such as a root or a stem, they are far too large. In such cases, microscope sections have to be prepared. The way to do this will be described as occasion arises.

In all cases, however, the object should be placed on a clean glass slide, and mounted in a mounting medium such as water or glycerol (formerly known as glycerine). There is, of course, the risk of some of the liquid medium getting on to the lens of the objective; so this is prevented by covering the mounted object with a thin sheet of glass, which is either rectangular or square. Objects should seldom be mounted dry, and never without a cover glass (or slip).

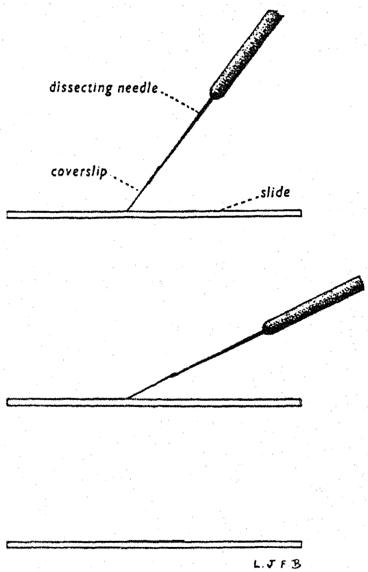


FIG. 92. METHOD OF LOWERING A COVER GLASS OVER MATERIAL MOUNTED ON A MICROSCOPE SLIDE.

It is useless to mount the object in water, then place the cover glass immediately on top, by means of the fingers, for air bubbles almost invariably appear in the medium. The cover glass should be held obliquely on the slide, near the object, then slowly lowered by means of a dissecting needle (see Fig. 92).

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1. Cut a bulb of the onion and, from one of the cut fleshy leaves, take off a portion of the very thin, tissue-like layer. Mount this in water on a slide and examine the structure of the cells. Make a drawing of a collection of such cells. Then examine one cell in detail under the high power of the microscope. In order to do this, it is best to stain the cell contents. This can be done by placing one drop of iodine solution over the edge of the cover slip, and drawing the solution under the cover slip by placing a little blotting paper on the opposite edge.

Note the protoplasm enclosing several large vacuoles; also the

nucleus, which, normally colourless, is now coloured a pale yellow by the iodine solution. Note the thin cellulose cell-wall which is surrounding the whole cell.

2. Remove a very small portion of the pulpy tissue immediately beneath the skin of a tomato fruit (enough to cover a pin's head is sufficient). Mount this on a slide in water and then tease it out by means of dissecting needles. Cover it with a cover slip and examine under the high power of the microscope. Note the small parenchymatous cells. Stain with iodine and examine the structure in detail.

3. Similarly remove a little of the green powdery *Protococcus* plants from a piece of damp wood and examine the single cells (see Fig. 2). Stain with iodine solution. Note the cell surrounded by the cell-wall. Note also the cytoplasm, and nucleus, and the flat, irregularly shaped chloroplast, packed within the cell. Look for colonies of such cells.

4. Take a very small portion of the gritty tissue of the pear fruit and tease it out on a slide. Examine the structure of the stone cells. Note the absence of cytoplasm and look for simple unbranched and branched pits. Staining with iodine or aniline sulphate (or chloride) will show up the lignified layers more clearly.

5. Obtain a prepared slide of a transverse section and a longitudinal section of a stem (a good example is that of *Cucurbita*). In these prepared sections examine, draw and describe as many conducting elements (sieve tubes and various types of tracheids and vessels) as is possible in transverse and longitudinal section.

6. Prepare some slides of various woody elements by maceration. The material required is a small woody twig. Cut up a portion of this into very fine pieces, then place the pieces in a beaker or crucible. Cover with concentrated nitric acid and add a few crystals of potassium nitrate. Warm this in a fume cupboard. When the reaction has finished, remove all the acid by repeated rinsing with water. Then mount some of the tissue and tease it out. Identify, draw and describe as many different examples of conducting and strengthening elements as you can.

7. Similarly macerate a small piece of wood of poplar. Look especially, in this case, for some examples of vessels with bordered pits. Examine the detailed structure of a bordered pit and make drawings to show the structure.

CHAPTER VI

FOOD OF LIVING THINGS AND SOME OF ITS BY-PRODUCTS

ALL living things must have an ample supply of food if they are to remain healthy. If they get an inadequate supply of food they soon show signs of malnutrition and become very unhealthy. They also become more susceptible to disease ; for an under-fed organism is much less resistant to disease than a well-fed one. Many plants and animals store excess food as a precaution against adverse circumstances.

Strange though it may seem, in general, the food of plants and animals is the same. That is why, for example, many animals feed on plants.

Food-stuffs may be classified into five great groups : **water, mineral salts, carbohydrates, proteins, and fats.**

Water

All plants and animals require water. We know this already, for water is the chief constituent of protoplasm. Apart from this connexion, however, water is very essential, for various purposes.

Many plants, for example, have to transport their manufactured food-stuffs from one place in their bodies to another, and it is always carried in solution in water. The transporting of food throughout the plant is called **translocation** (see Chap. XII).

In the digestion of food, too, water is necessary. Also, all the chemical changes which occur in the living cell (and there are many) do so in solution in water, and many chemical reactions in the cell involve molecules of water.

The amount of water required by a plant varies with the plant. That is why some cultivated plants require more watering than others. A potted plant of heather, for example, should

not be watered too frequently—perhaps once every few days; whereas a *Cineraria* should be watered at least once a day. If the familiar *Pelargonium* be watered too much the leaves become yellow and the plant sickens and dies. In man, about sixty per cent. of his body-weight is made up of water. In very dry seeds the water content is very low, whereas that of some seaweeds is as much as eighty per cent.

Water is continually being lost by the plant and animal. In the latter, this takes place chiefly through the urine, lungs, sweat and excreta; and in the former, it is given off into the air as

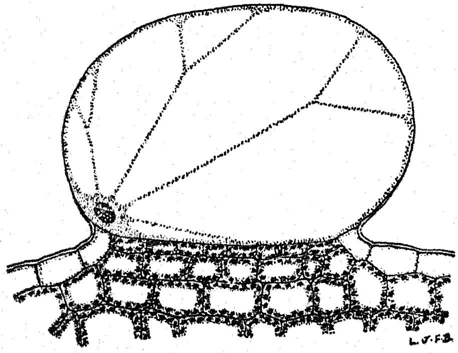


FIG. 93. SECTION OF A PORTION OF THE LEAF OF *Mesembryanthemum*.
One of the outer cells has become very much enlarged, for water storage.

water vapour through the leaves (see Chap. XII). This water has to be replaced by absorption from the soil through the roots.

In some extreme cases, water is stored in special storage cells. These cells often take the form of enlarged hairs on the outer layers of the leaf, as in the case of the ice plant (*Mesembryanthemum*). This plant is familiar in rockeries, and the water-storage hairs on the leaf glitter and make the plant look as if it is covered with a layer of ice. Hence its popular name (Fig. 93).

Some plants, such as **lichens**, can withstand desiccation for a long time.

Submerged plants, such as *Chlamydomonas* and seaweeds, absorb their water supplies all over their surface. Partly sub-

merged plants, such as sedges and water-lilies, absorb it by means of their roots and also those parts of the stem and leaf petioles which are under the water. Terrestrial plants absorb their water from the soil through their roots; and in the case of aerial plants, the water is condensed on the aerial roots and absorbed in that way.

Mineral Salts

Until comparatively recently it was not realised how important certain inorganic mineral substances are to life. We ourselves, for example, must have some inorganic substances, such as sodium, iron, calcium and phosphorus salts. Common salt and iron are in the blood, phosphorus in the brain and nerves, and calcium in the bone.

Plants require many elements for their foods also. Hydrogen and oxygen are obtained from the water. Carbon is absorbed from the air (see Chap. XI). All the rest are obtained from the soil. Nitrogen, for example, is required in all types of proteins. Phosphorus and sulphur are required for certain proteins; magnesium is one of the elements present in chlorophyll. Iron, calcium, potassium and certain other elements too are necessary to a plant.

All these elements, together with others, with the exception of hydrogen, oxygen and carbon, are absorbed in chemical compounds from the soil. The chemical compounds pass into the root, dissolved in the water. In the case of submerged plants, there is sufficient quantity of the compounds in the sea- or fresh-water (whatever the case may be) for the plant, and they are absorbed in the dissolved state all over the surface of the plant.

There are many more chemical substances in the water than the plant requires, and it is astonishing how the plant can select what it wants and reject what it does not want. For example, in sea-water there is a high percentage of common salt (about 2·7 per cent.) but an infinitesimal amount of iodine. Yet brown seaweeds absorb a much greater ratio of iodine. For this reason, the brown seaweeds are used, to a considerable extent, as a commercial source of iodine.

Iodine was first extracted from seaweeds in 1812. The seaweeds are collected and dried in the sun and then placed in shallow pits and burned. The ash is called **kelp**, and from this kelp, iodine and other salts are extracted. A new method of obtaining iodine from seaweeds involves placing the seaweeds in tanks until they rot. Then the liquid formed is evaporated. The residue is rich in iodine salts and potash salts. The remaining solid material can be used for paper-making, since it is composed chiefly of cellulose.

Chemical analysis of plants is the chief way in which the necessary elements are discovered. The usual way to analyse plants chemically is to obtain the plant ash. A large number of plants are required, for the amount of ash from one plant is very small. The plants are spread in a large room, where they are allowed to wilt and die, until they become quite brittle. Then they are powdered, usually by passing through a sieve, and the plant powder is heated in a crucible until all the volatile material is driven off. In this way all the carbon, hydrogen, oxygen and much of the nitrogen are driven off and the rest of the elements remain. These are analysed by the usual chemical methods.

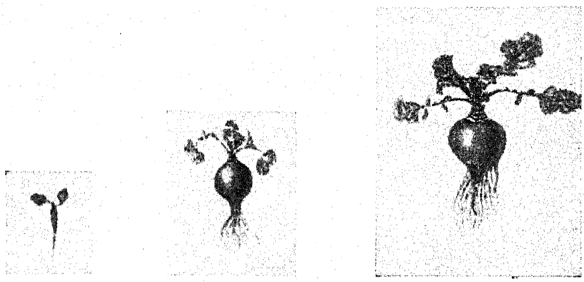
Cultures and Manures

The *reasons* for the necessity of these elements to the plant are studied by means of **cultures.** The most reliable method is that of **soil culture.** This method has many varieties. By far the best is that carried out in the field, and this is done in many research stations, such as **Rothamsted Experimental Station** in Hertfordshire.

Nearly all civilised countries throughout the world support experimental stations, situated in suitable surroundings, where problems concerning plants, such as cultivation, manuring, diseases, storage, breeding and transport, are studied by experts. The great merit of such stations is that the studies can take place in the field, that is, under natural conditions instead of the artificial conditions of the laboratory.

Such widespread experimental study of plants, as a national necessity, is only of comparatively recent origin. Rothamsted

Experimental Station, for example, was founded by **Sir J. B. Lawes** as the outcome of experiments begun in 1834. These took the form of attempts in the field to discover the effects of various substances or fertilisers on plant growth by adding them to the soil. But Lawes's most important work was on what is now called **superphosphate**, an artificial manure obtained by treating calcium phosphate with sulphuric acid. He patented this process in 1842, and thus initiated the artificial manure industry. The phosphate used to-day, for treatment with sulphuric acid in order to produce superphosphate, is ground rock phosphate.



Grown without manure. Grown with manure supplying phosphates and potash. Grown with manure supplying phosphates, potash and nitrates.

FIG. 94. TURNIPS GROWN ON ADJACENT PLOTS OF LAND.
(By kind permission of the Royal Agricultural Society of England.)

Nearly half a million tons of this substance is imported into Great Britain annually for the purpose. Lawes's work led to the establishment in 1843 of a factory for producing artificial fertilisers for crops. Now, artificial manures are used all over the world. Some results of testing the effects of artificial manures, in field experiments, are shown in Figs. 94 and 95.

Rothamsted Experimental Station is now directed by **Sir John Russell**, who has under his supervision a large staff of botanical, chemical and agricultural experts who are busy attacking many of the serious problems in plant cultivation.

Instead of field experiments, another variety of the soil culture method is to grow plants in pots. This method may be used for discovering what elements are necessary to plants. It would be

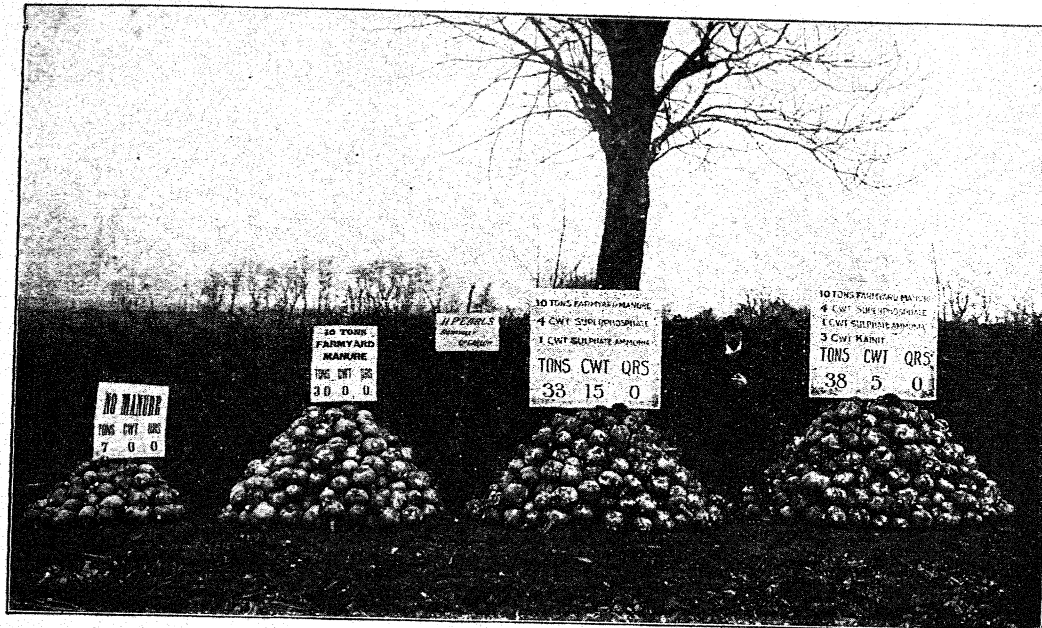


Fig. 95. Results of supplying Swede Turnips with various Manures.

hopeless, of course, to put ordinary soil in the pots, for such soil already contains the necessary elements. A *sterile* soil is necessary, to which the elements may be added afterwards in controlled quantities. A sterile soil can be made of powdered carbon or quartz or fine sterilised sand. To this the culture solution is added.

The second method of approaching the problem is more convenient in the laboratory. It is called the **water culture** method. Many plants can grow quite successfully with their roots immersed in water instead of the soil. The water must, however, contain dissolved air. For experimental purposes, a good plant to use is the broad bean (*Vicia Faba*). Details for performing culture experiments will be found at the end of the chapter. In these experiments, instead of putting pure water in the vessel, a solution of all the elements necessary to a plant if it should grow healthily is used. There are several prescriptions for a culture solution. One of the first proposed was that of **Knop.** This consists of 100 c.c. distilled water, 1 gm. calcium nitrate, 0·25 gm. magnesium sulphate, 0·25 gm. acid potassium phosphate, 0·25 gm. potassium nitrate and a few drops of ferric chloride. This solution therefore, besides containing the elements hydrogen and oxygen of the water, contains calcium, nitrogen, magnesium, sulphur, potassium, phosphorus, iron and chlorine.

A plant grown in distilled water does not last long, as experiment shows. One grown in this culture solution, however, grows and remains healthy. This proves that the above elements are necessary to a plant. The experiment can be carried still further to see what is the effect of the absence of any of these elements. For example, if instead of magnesium sulphate, magnesium chloride is substituted, the element sulphur is eliminated from the solution. Varieties of this experiment give some interesting information. For example, if potassium be omitted the plant becomes dwarfed and cannot resist disease ; the omission of calcium allows the plant to be easily poisoned ; and that of iron prevents the plant from becoming green. This last case, that of the prevention of chlorophyll manufacture, is called **chlorosis** and the plant is said to be chlorotic.

The phenomenon of chlorosis due to the absence of iron from the nutrient salts is very interesting, for from such an observation one would naturally conclude that iron is therefore present as one of the elements in chlorophyll itself. Actually this is not the case.

Some plants require more of certain elements than others do, and some soils contain more of such elements than other soils do. That is one of the reasons why one soil is good for one crop and another soil is good for another crop. Some results of culture experiments in pots (sand culture) and glass vessels (water culture) are illustrated in Figs. 96 and 97.

Natural Manures

Another problem arises in connexion with this consideration; that is, the problem of **leaching** in the soil. By the process of leaching, elements in the soil become reduced in quantity, either by being dissolved out by rain water, or by the action of the acids present in the soil, or by the plants themselves absorbing them.

The question therefore is: how are the elements to be prevented from being leached out too much, and how are they to be replaced? In naturally occurring plant regions, such as meadows and forests, this is done by the plants themselves and also animals. When these living things die, their remains act as a natural manure, which is called **humus**. This is acted upon chemically (see Chap. VIII) and reduced to the original chemical compounds, which are washed back into the soil by the rain.

In agricultural and horticultural cultivation this is not the case, since the plants are removed from the soil for use. In this case, the elements are replaced by manuring. Natural manure such as leaf mould or animal dung is added to the soil, either by being placed on the soil surface and left to be washed in by the rain or by actual digging into the soil. Sometimes, however, this method does not supply enough of the necessary chemicals, and then artificial manures or fertilisers are used. These artificial fertilisers were first used extensively by Lawes. Artificial manures which contain nitrogen, phosphorus and potassium are

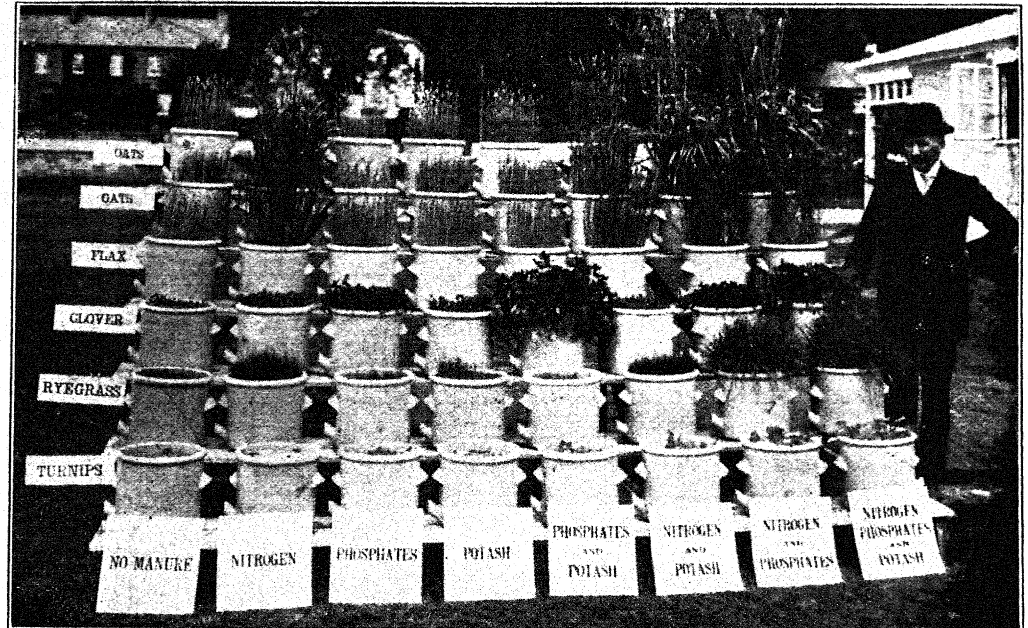


FIG. 96. POT EXPERIMENTS, SHOWING THE RESULTS OF MANURING.

used to a great extent in modern farming and gardening. The best-known nitrogenous fertilisers are Chile saltpetre and ammonium sulphate, the latter being obtained from gasworks

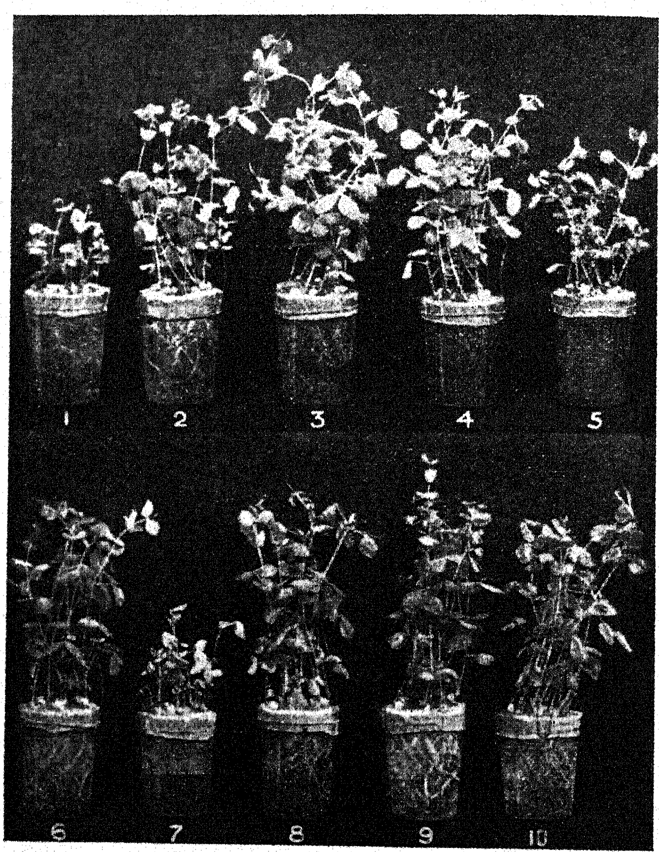


FIG. 97. WATER CULTURES OF FIELD PEAS.

1, distilled water; 2, tap water; 3, Knop's solution; 4, Knop's solution without nitrogen; 5, Knop's solution without phosphorus; 6, Knop's solution without potassium; 7, Knop's solution without calcium; 8, Knop's solution without magnesium; 9, Knop's solution without iron; 10, Knop's solution without sulphur.

(*After Duggar.*)

or manufactured by a process in which nitrogen from the air is heated under pressure with hydrogen, so that the two elements combine together. This manufacture of fertiliser from atmospheric nitrogen is carried out on a large scale at the works of the Imperial Chemical Industries, Ltd., at Billingham, Durham.

In spite of the great advantages of artificial manure in crop production, natural manure, such as farmyard manure, is much

FIG. 98. EIGHT-YEAR-OLD WHITESMITH GOOSEBERRY PLANTS.
On the right, not manured in year of planting; on the left, manured with farmyard manure in year of planting. The scale is in feet.
(Photo. East Malling Research Station.)

more successful in almost all types of plant production. The effect of ordinary farmyard manure on a gooseberry plant is shown in Fig. 98. The superiority of farmyard manure over artificial manure was proved by extensive field experiments at Rothamsted Experimental Station and is illustrated graphically in Fig. 99.

Sometimes soils are too acid. This is counteracted by adding lime.

Of interest in connexion with the extensive manufacture and use of artificial fertilisers is the dying-out of the starfish industry around the estuary of the Thames. Until recently, starfish were collected by the ton in the Thames estuary for two reasons: first, this animal was a nuisance to the oyster industry which flourishes in that region, since the starfish preys on the oyster: and secondly, the starfish was sold to the farmers of north Kent and south Essex and placed in the soil as a manure. Now the industry has almost disappeared for two reasons: first, the use of artificial (chemical) manures instead; and secondly, the starfish are not present in the estuary to

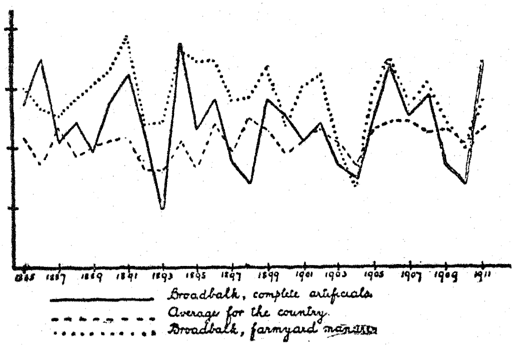


FIG. 99. YIELDS OF WHEAT, IN BUSHELS PER ACRE, FROM THE BROADBALK FIELD, ROTHAMSTED.

Manured with complete artificial manures and with farmyard manures respectively. These are compared with the average yield for the whole country between the dates indicated.

(*From "Nature," after Sir John Russell.*)

anywhere near such an extent since they have been driven further out to sea by the pollution of the River Thames, chiefly by shipping.

Rotation of Crops

Since some plants require more of certain elements than others, it would seem advisable never to grow the same kind of plant on the same soil in two consecutive seasons. In the second season, another type of crop should be planted, and in the third another,

and so on. Such a changing round of crops is known as the **rotation of crops**, and has been practised in agriculture since before Roman times. Although it is not used quite so much in gardening practice it would be better if it were. By this rotation of crops, one crop is alternated with a 'recuperative' crop. In one season a grain crop is grown, and in the next a root crop.

What is called the 'four-course system' is still used extensively in agriculture. In this system, the rotation is wheat one year, then roots (such as swedes) in the next, then barley and then clover. The last-named is often used for a special purpose, as will be seen in Chap. VIII.

Carbohydrates

Carbohydrates are common constituents both of plants and animals. They are useful to animals in that they are more easily digested, that is, they are more easily made soluble and thus ready for absorption into the system than proteins and fats are. They are therefore prescribed for people suffering from weak digestion.

The name **carbohydrate** was given in the first place because it was discovered that these substances contain the elements carbon, hydrogen and oxygen, the last two being present in the same proportion as they are in water, that is, two parts by volume of hydrogen to one part of oxygen. We now know, however, that this name is erroneous, for there are some carbohydrates in which the elements do not conform to this proportion. Nevertheless, the name still holds.

Carbohydrates, besides being an essential constituent of protoplasm, exist as food reserves such as **sugars**, **starches**, and also in the plant cell-wall as **cellulose**. In animals, they seldom exist other than in the cell protoplasm.

Carbohydrates may be roughly classified into two groups, namely, **sugars** and **non-sugars**. All of them have high molecular weights, but those of the non-sugars are much higher than those of the sugars. Sugars are usually sweet to the taste and are soluble in water, whereas the non-sugars are not.

Sugars

Sugars are very common in plant and animal tissues. For our purpose, the consideration of one or two will be sufficient; but it must be realised that there is quite a large number of them.

One of the simplest sugars is **glucose**. It is a brownish crystalline substance with the formula $C_6H_{12}O_6$. It is present as a food reserve in the fruit of the grape (hence its common name, grape-sugar), the onion bulb and onion seed and various leaves and roots of many plants. It is usually present in these cases in solution in the cell-sap of the vacuole.

Commercially, this sugar is of some importance, though its sweetness is only about two-thirds that of the ordinary cane-sugar, used in cooking and at the table. It is used for sweetening the cheaper brands of jam and beer and, in the United States especially, it is used in ice-cream, chewing-gum and condensed milk.

In the grape, glucose plays a very important rôle commercially. As we shall see in Chap. XIII, some sugars can undergo the process of **fermentation** whereby they are converted into alcohol and carbon dioxide according to the equation

$$\underset{\textit{sugar}}{C_6H_{12}O_6} \rightarrow \underset{\textit{alcohol}}{2C_2H_5OH} + \underset{\textit{carbon dioxide}}{2CO_2}$$

In the ripe fruit of the grape, grown in warm countries such as France, the sugar content ranges from 25 to 35 per cent. By fermentation this is converted into alcohol during the process of wine-making.

Glucose is also present in the human blood. When a person suffers from the disease called sugar diabetes, there is excess of this sugar which is given off in the urine. The disease can be diagnosed by testing the urine. By medical men, this sugar is called 'diabetic sugar.'

A much more familiar sugar is cane-sugar or **sucrose**. It has the formula $C_{12}H_{22}O_{11}$. This sugar is very common in nearly all the organs of plants, especially the leaves. It is present in varying amounts, but in some plants the percentage is high enough to

make it worthy of extraction. In the sugar-cane (*Saccharum officinarum*), a plant grown for the purpose in tropical lands (Fig. 100), the sucrose content of the stem is about 20 per cent. In the root of the sugar-beet (*Beta vulgaris* var. *Rapa*) it is 10 to 20 per cent. and it is also high in the birch (*Betula*) and maple (*Acer saccharum*). Sucrose and glucose are present together in many so-called 'fruits.' There is more sucrose than glucose in

FIG. 100. CUTTING SUGAR CANES IN JAMAICA.
(*From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.*)

the pineapple, strawberry and apricot; but the reverse is the case in the banana and the apple.

The sugar-cane is grown from cuttings. In the American and West Indian plantations the cuttings are planted in October, and after 20 to 24 months the first crop is taken; two years after, a second crop is ready. Then, in accordance with the rotation of crops, maize is usually sown. After the canes are cut they are transferred to the mills, where the juice is extracted by passing them through rollers. The juice is boiled with milk of lime in order to neutralise any acids present, and then it is treated with

sulphur dioxide. The liquid is then allowed to concentrate by evaporation and the crystals produced form brown sugar. The white sugar is obtained by a process of refining.

When the beet is used, the sugar is dissolved out of the root by slicing it and immersing the slices in water. Sugar-beet is now cultivated in certain parts of Great Britain, and, for various economic reasons, the industry is given a subsidy by the State in order to encourage its development.

The residue left after the majority of the sugar has crystallised out of the sugar-cane is called **treacle or molasses,** which forms an article of diet. It is also used in the making of rum, cattle food and boot blacking. In the case of the sugar-cane, the pressed canes are used for fuel, and in the case of the beet, a by-product called **spent char** which is used as a fertiliser.

Two American scientific workers have found that if about 6 per cent of cane-sugar be added to ordinary lime-sand mortar, the tensile strength of the mortar is increased by 60 per cent. The sugar is added dissolved in water after the lime has been slaked. With sugar at a low price, this discovery should have some practical value.

The sugar-cane is now responsible for about 65 per cent. of the world's supply of sugar, and the sugar-beet for 35 per cent. On the average, 27 million metric tons are produced annually throughout the world. The most important sugar-cane countries are Cuba (18 per cent. of the world's supply), India (12 per cent.) and Java (10 per cent.); whereas the sugar-beet countries are Germany (6·7 per cent.), U.S.S.R. (4·5 per cent.) and Czechoslovakia (4·5 per cent.).

Non-Sugars

Non-sugars are characterised by their high molecular weight and insolubility in water. Starch and cellulose are two very common ones in plants and they are both of commercial importance. There are several other non-sugars.

Starch is insoluble in water and therefore cannot exist in solution in the cell-sap like the sugars do. The chemical formula for starch is still very uncertain. Its empirical formula is $C_6H_{10}O_5$, but we can only say that the molecular formula is $n(C_6H_{10}O_5)$.

where n is still unknown. We know it is a high number, probably about 40, so that the molecular weight is very high.

Starch is present in leaves, stems, roots and storage organs such as the potato tuber and tulip bulb. Some plants, such as the onion and the bluebell, however, do not contain starch, but contain a great deal of sugar.

Starch takes the form of microscopic grains in the plant, embedded in the cell cytoplasm. These grains vary considerably in shape, so much so that from a microscopic examination of them it is often possible to say from which plant they have been extracted. They vary in size too, from about 0·002 mm. to 0·17 mm. in diameter.

Starch grains are not merely homogeneous masses. They are formed of several layers or **stratifications**, thick, dense layers alternating with thin, less dense ones. The centre around which these layers are deposited is called the **hilum**. Sometimes two starch grains begin development near each other, then as the successive layers are deposited the growing grains touch each other and the succeeding layers are deposited around both grains, thus forming a **compound** starch grain with two hila. Sometimes there are three or even four hila. The normal grain with only one hilum is called a **simple** starch grain (Fig. 101).

Starch as a commercial product is very important. Physically it is a colloid, and for that reason it is used in making pastes, for the glutinous nature of pastes and gums depends upon their colloidal properties. In laundry work, starch is used for stiffening materials such as cuffs, collars, serviettes and dress-shirt fronts.

The most important economic use of starch, however, is the same as in the plant, that is, as a food. It is the fundamental food present in many articles of diet such as the potato tuber, artichoke tuber, flour (with proteins), haricot beans (with proteins), peas (with proteins), arrowroot, sago, tapioca.

Arrowroot is a product of the rhizome of *Maranta arundinacea*, a plant grown in the tropics, especially in Brazil, Guiana and the West Indies (Fig. 102). Starch is present in the rhizome to the extent of 25 per cent. The product was once used by the South American Indians as an antidote for wounds made by poisoned

arrows: hence the name. The rhizomes are peeled and pulped. The starch is extracted by washing and then drying the extract.

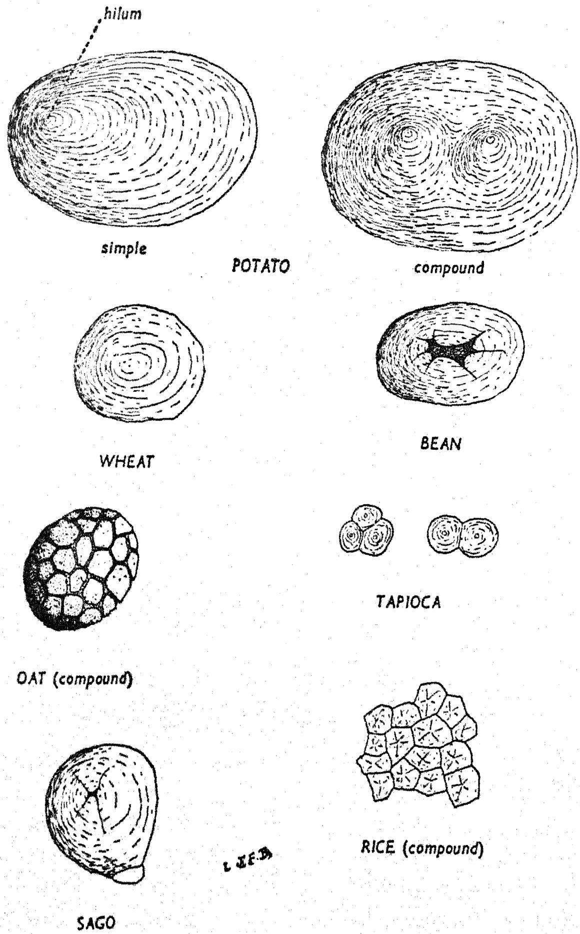


FIG. 101. TYPES OF STARCH GRAINS.

It is an easily digested food, and is therefore used by patients with digestive trouble. It is also used for thickening soups.

Starches from many other plants are now used for making so-called arrowroot.

Maize grains are comparatively small. They are used in the manufacture of **cornflour.** Potato starch grains are ovoid in shape and larger than the maize grains. In extraction, 100 lb. of potatoes yield about 16 lb. of dry starch. **Rice** starch grains

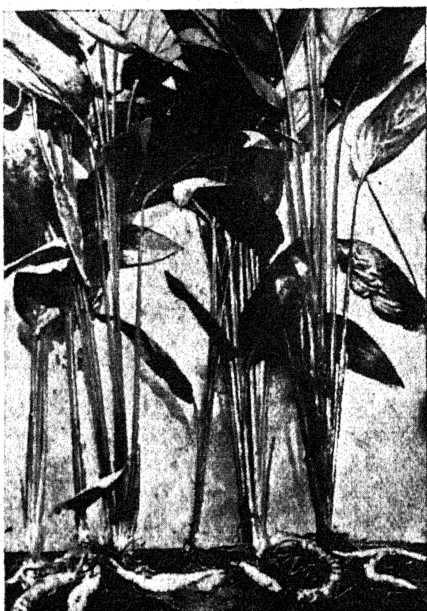


FIG. 102. ARROWROOT PLANTS SHOWING THE RHIZOMES.
(From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.)

are extremely small and misshapen. Rice starch is used extensively in laundry work. 100 lb. of rice yields 85 lb. of dried starch—the highest percentage known. **Sago** is a starchy preparation made from the pith of the sago palm. Here the grains are similar to those of the potato, but have very obvious fissures on their surfaces. **Tapioca** grains are small and are extracted from the root tubers of the cassava plants (*Manihot utilissima*) which are cultivated in the tropics. Careful washing is necessary

in the case of tapioca since the plants contain a slight trace of prussic acid (HCN), which is a strong poison (Fig. 103).

Wheat starch is smaller and the grains are not so well shaped as those of potato starch. The grains of wheat are ground into **flour** by the miller and the flour is used for several purposes, the

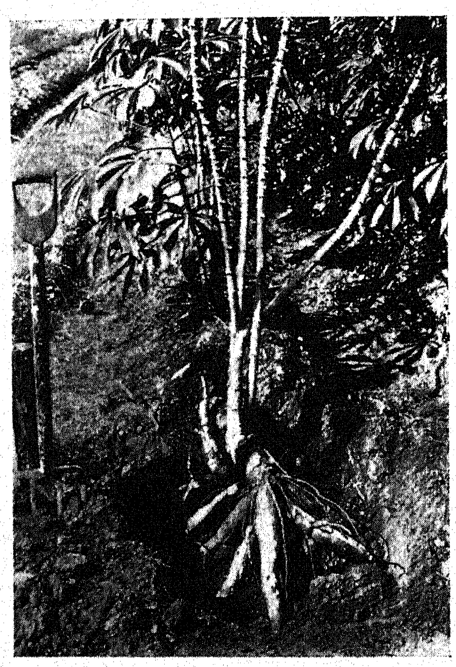


FIG. 103. CASSAVA PLANT SHOWING THE ROOT TUBERS.
(From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.)

chief of which is baking. Flour is highly nutritious, for it contains not only starch but also protein. There is about four times as much starch as protein.

Starch and protein are the main constituents of the food reserves of many cereals such as wheat, barley, oats, rye, maize and rice. These cereals have formed articles of diet for man and animals for many centuries, both in civilised communities and amongst savages. Other food-stuffs which have become fashion-

able in more recent times also contain starch and protein, such as **macaroni**, **vermicelli** and **spaghetti**. These foods are made from flour obtained from a special kind of wheat, which will be considered later in this chapter.

Gums are very complicated carbohydrates, chemically. Some gums will dissolve in water to form adhesive substances. Others will not dissolve but will absorb water and form a jelly. **Gum arabic** is obtained from a plant (*Acacia Senegal*) which grows in the Sudan and is used in finishing silks and other textiles, in the making of wall-paper, the preparation of water colours, and a host of other processes. **Gum tragacanth** is extracted from certain plants (*Astragalus*) which are cultivated in Greece and Turkey and is used in the thickening of colours used in calico printing, in medicine as a vehicle for certain insoluble powders, and in the pottery trade as a colour adhesive. **Chewing-gum** is obtained from a plant, *Sapota achras*, which grows in tropical America. It is sweetened by the addition of glucose and flavoured by different essences, such as that of mint.

Cellulose and its related substances are of great importance to the plant, and also economically to man. It is not a very important food reserve in plants. Nevertheless, in some cases it does form an important food reserve. The purest cellulose is present in the cell-wall of the plant. The normally unthickened cell-wall contains a very high percentage of cellulose; therefore some plants store their food merely by producing very thick cell-walls in the food-storing tissue, which is usually the seed in such cases. This is so in the date palm and several other plants (Fig. 104).

Cellulose is chemically a carbohydrate, but, like starch, its exact composition is at present unknown. All that can be said at present is that it has a formula $n(C_6H_{10}O_5)$, where n is unknown. In 1934 it was estimated that the molecular weight of native cellulose is about 300,000. Therefore the molecule is a very large one.

The **cotton** plant (*Gossypium*) is the chief source of cotton in industry. The uses of cotton are so well known that they scarcely need consideration now. Cotton is composed chiefly of cellulose

which is present in the cell-walls of certain very long cells which grow on the seeds of the plant, forming a very hairy covering (Figs. 105 and 106).

About 60 per cent. of the world's cotton is produced in the United States, 18 per cent. in India and 6 per cent. in Egypt.

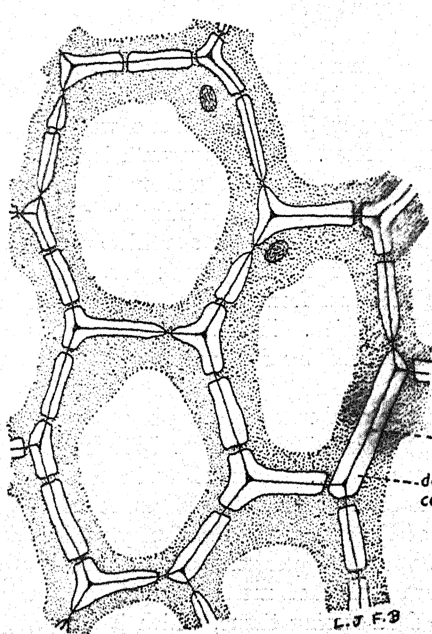


FIG. 104. CELLS OF THE SEED OF *Impatiens Balsamina*, WITH CELL-WALLS THICKENED WITH CELLULOSE AS A FOOD RESERVE.

Cotton has been known from time immemorial, and was in use in India so far back as 1500 B.C. (Fig. 107).

The cotton plant requires a warm, damp atmosphere and plenty of rain during the young stages of its growth. By a process of irrigation the young plants are absolutely flooded, and later this water is drained off. In the actual manufacture of the cotton textile, a very humid atmosphere is required and a not too high temperature. This is to prevent the slender cotton threads

from breaking during the process. That is why Lancashire is such a good cotton-manufacturing centre. Nowadays, the atmosphere of the rooms of the cotton mills in which the looms are working is kept humid either by flooding the floors with water or by introducing steam into the atmosphere through jets. Sometimes both methods are used, but the latter is the more modern method.

FIG. 105. FLOWERS OF THE COTTON PLANT.
In the bottom right-hand corner is a pod with its hairy seeds exposed.

Apart from almost pure cellulose there are many very impure types called **compound cellulose.** These are of great importance to the plant. Compound cellulose is composed of cellulose together with other chemicals which are not carbohydrates. **Wood,** for example, is formed of cellulose united with a substance called **lignin** and also other substances. This forms the basis of the structure of vessels, tracheids, fibres and stone cells. Wood is used for many purposes. The woody fibres of the **jute** plant (*Corchorus*), which grows chiefly in and around India, are used in the manufacture of carpets, tapestries and ropes. **Straw** is

formed from the dried stems of cereals and composed chiefly of pure and compound celluloses. Large masses of woody tissue, used as timber, have already been considered.

Apart from the fundamentally important and well-known uses of cellulose and compound celluloses, these carbohydrates, when treated in various ways, have many other industrial uses. Cellulose is the chief raw material in **paper-making**. Paper is made either from cotton waste (rags) or from wood pulp—chiefly the latter nowadays. In the latter case, the lignin is re-

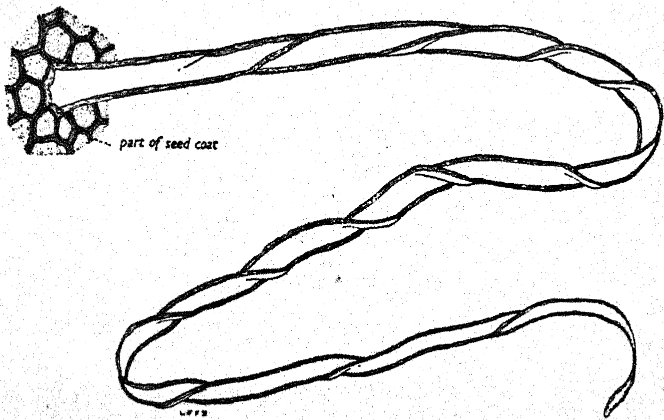


FIG. 106. A SINGLE HAIR OF THE COTTON SEED, WHICH FORMS THE RAW MATERIAL FOR THE MANUFACTURE OF COTTON. NOTE HOW THE HAIR TWISTS. (× 300.)

moved first by treating the pulp with carbon disulphide, thus leaving the comparatively pure cellulose behind.

Some **incandescent lamp mantles** and **electric lamp filaments** are prepared by treating cellulose with zinc chloride. The syrup is forced through glass nozzles into alcohol and then afterwards washed and carbonised.

Cotton waste, when treated with one part of nitric acid to three parts of sulphuric acid and the resulting mass dried, forms the explosive called **gun cotton**.

Blasting gelatine, used in blasting operations, is a mixture of gun cotton and nitroglycerine.

Cellulose is also used in the manufacture of **india-rubber, celluloid, artificial silks, viscose** (a substance used in sizing paper and in the manufacture of wall-paper), **viscoid** (used in the manufacture of cheap mouldings and statues), **cellulose acetate** (for dressing the fabric of aeroplane wings and for dress material known as **rayon**), **cellite** (for the manufacture of non-flammable cinematograph films) and water-proof (**Willesden**) paper.

FIG. 107. A COTTON PLANTATION IN THE SUDAN.
(Reproduced by kind permission of the Controller of H.M. Stationery Office.)

Proteins

Proteins are the most important constituents of protoplasm. The term 'protein' comprises a large variety of substances occurring in the plant and animal kingdoms. There is quite a high percentage of proteins in milk. The 'white' of an egg is composed mainly of protein and water, the chief protein being called **albumin**. The lean part of meat is composed chiefly of different proteins; so also is the flesh of fish.

In plants, proteins occur either as solids or in the colloidal condition in the cell-sap. Apart from the proteins which form the main part of protoplasm, these food-stuffs are often present

as reserves in almost any part of a plant, especially in seeds and vegetative organs of reproduction such as the potato tuber. In this organ, the reserve proteins are present chiefly in those parenchymatous cells immediately beneath the epidermis or skin. That is why potatoes which are cooked in their 'jackets' are more nourishing than potatoes which have been peeled.

Solid proteins are sometimes amorphous and sometimes crystalline. A very special kind of protein reserve is present in the seed of the castor-oil plant (*Ricinus communis*) and in other seeds. In this case, several proteins unite to form an ovoid structure called an **aleurone grain** (Fig. 108). Under the micro-

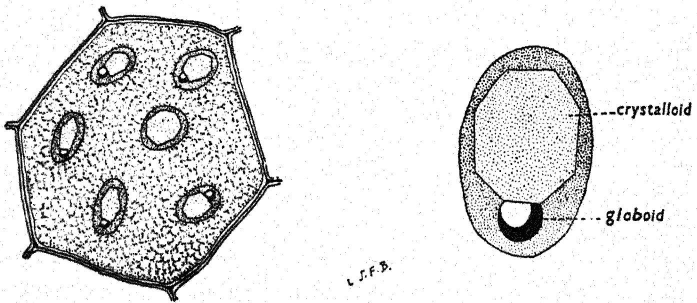


FIG. 108. LEFT, ALEURONE GRAINS IN A CELL FROM THE SEED OF THE CASTOR OIL PLANT (× 550) ; RIGHT, A SINGLE ALEURONE GRAIN (× 1800).

scope, this structure appears as an egg-shaped matrix in which is embedded two smaller structures. One of these forms a crystal shape. This is composed of protein and is called the **crystalloid.** (This term must not be confused with the term which we have already used in contradistinction to the term colloid). The other structure within the matrix of the aleurone grain is spherical in shape and is therefore called the **globoid.** This is not a protein, but is composed of the double phosphate of calcium and magnesium. The matrix in which the crystalloid and the globoid are embedded is composed of protein which is different from the protein of the crystalloid in that it is chemically much simpler. Surrounding the whole aleurone grain is a thin skin which is formed of a different protein again.

In the potato, the proteins are chiefly solid, forming cubical crystals.

Proteins are very common in cereals, especially the grains, such as maize and wheat; hence flour is composed chiefly of protein and starch. Proteins also form the chief food reserve in pea and bean seeds.

All proteins contain the elements carbon, hydrogen, oxygen and nitrogen, and many types also contain phosphorus or sulphur.

Proteins form a very common article of diet. They are present in a very high percentage in **lean meat, milk, eggs,** and, of course, many **vegetables.** Flour contains different proteins, the chief of which is **gliadin;** therefore such manufactured foods as macaroni, vermicelli and spaghetti have a high protein content, since these foods are manufactured from flour. For these products a certain type of wheat is grown, chiefly in Mediterranean countries. The flour obtained from this wheat is milled to a medium thickness, mixed with boiling water, and kneaded to a dough. There is a high percentage of **gluten** (a protein) in this special flour and this makes the dough very stiff. The dough is then transferred to a large press and forced through openings of the required size. According to the size and shape of these orifices, so we get macaroni, vermicelli, or spaghetti. The products are then dried in special drying rooms and are used as an article of diet, especially by Mediterranean peoples. These foods are also eaten by diabetics owing to the large amount of digestible gluten which they contain.

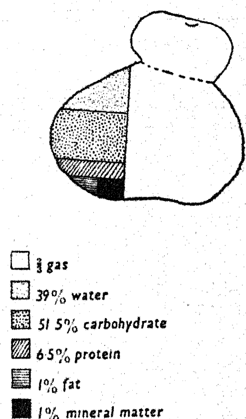


FIG. 109. THE PERCENTAGE COMPOSITION OF A LOAF OF BREAD. (*After Mottram and Hutchison.*)

Fats and Oils

There is no fundamental difference between fats and oils. Both names are only general ones, a fat denoting a solid and an

oil denoting a liquid, under the normal conditions of temperature, etc. Apart from this, fats and oils are very similar.

Each name denotes a group of many substances which, apart from being important constituents of living protoplasm, form important food reserves in plants and animals. Many animal fats are very familiar, and their uses are equally as well known.

All fats contain the elements carbon, hydrogen and oxygen, but, of course, not in the same proportion as they are in the carbohydrates. Fats are formed by the chemical reaction of a fatty acid, of which there are about a dozen important ones, with the well-known substance **glycerine** or **glycerol**, which is actually one of the alcohols.

The specific gravity of all oils and fats is less than that of water, and they are all insoluble in it; but they are soluble in chloroform, ether, carbon disulphide and carbon tetrachloride. The majority also make a translucent mark on paper.

Oils are often found as food reserves, usually in parenchymatous cells as small droplets suspended either in the cytoplasm or the cell-sap. They occur in all types of plants, from the seaweeds upwards. In angiosperms, fats and oils are found chiefly in seeds; for example, the Brazil nut, which is really a seed and not a nut, contains nearly 70 per cent. and the almond contains about 55 per cent.

Oils vary in chemical composition and for that reason they have different properties. For the same reason also, oils have all kinds of economic uses, such as illumination, lubrication, soap-making, foods and so forth.

Olive oil is extracted from the fruit of the olive (*Olea europœa*). The best olive oil is extracted by the mere pressure of the fruit and is used as a food, such as a medium in which to preserve other foods and also in salad oils and dressings. Inferior olive oil is extracted by dissolving it out in a fat solvent such as carbon disulphide, and this oil is used in making certain kinds of soap. **Cotton-seed oil** is extracted, as its name implies, from the seed of the cotton plant by pressure at a temperature of about 90° C. After purification it is used in the manufacture of **soap** and **rubber substitutes**. Not many years ago, cotton seed was considered a **waste** product and a nuisance. To-day it is a very important

agricultural product. **Coco-nut oil** is obtained from ripe coco-nut fruit (*Cocos nucifera*) (see Chap. XIX). Soap made from this oil is useful because it is one of the very few soaps which can absorb large quantities of salt water. It is therefore useful for washing in sea-water.

Palm oil is extracted from the fruit of one of the tropical palms (*Elaeis guineensis*) and has the consistency of lard. It is used in the manufacture of **margarine**. **Rape oil** is obtained from the seeds of *Brassica rapa* and is sometimes used as an **illuminant.** By heating it to 70° C. and drawing a current of air over it, the so-called 'blown oil' is produced. This will mix with mineral oils such as paraffin, and the mixture is used for the lubrication of marine engines. **Linseed oil** is obtained by pressure from the seeds of the flax plant (*Linum usitatissimum*). The residue left after pressure forms the well-known **oil-cake** which is used as cattle food. Linseed oil, and also **walnut oil** and **poppy-seed oil,** are used in **oil paints. Castor oil** is obtained by compressing the seeds of the castor-oil plant (*Ricinus communis*). It is used as a **medicine,** and is also a very valuable chemical in the **dyeing** industry.

Soap-making

Soap-making is an important industry. In Great Britain it is carried on chiefly in Lancashire and London. This industry depends on plant and animal fats as one of its raw materials. The fat or oil is boiled with caustic soda, during which the process of **saponification** takes place. Then the mixture is saturated with common salt and, since the soap will not dissolve in salt water, it rises to the surface, whereas the glycerol from the original fat remains dissolved in the salt solution. For hard toilet soaps, the following fats and oils are used: tallow fat (obtained from the fat of sheep, especially in Australia and New Zealand), palm oil, coco-nut oil, palm-kernel oil, and olive oil. Soft soaps are made from hemp-seed oil, cotton-seed oil and linseed oil.

The foregoing brief survey of the various types of substances which help to make up the plant body gives an idea of the

complicated chemical structure of plants. Animals, including ourselves, are built up of similar substances (in many cases, the same), therefore they too are extremely complicated organisms.

By consuming plants, animals absorb these food-stuffs. Therefore, the food, or **dietetic**, value of plants depends on (*a*) their own chemical composition and (*b*) what the animal consuming them actually requires. Fig. 109 shows in a diagrammatic form the percentage composition of ordinary bread.

PRACTICAL WORK

1. Soak some bean seeds in water for twenty-four hours. Then sow them in damp sawdust, and keep them well watered. When their shoots are just appearing above the surface, carefully remove the young plants, making sure that they are not damaged. Select three plants which are equally developed and sow one in a pot of sawdust, another in sand, and another in garden soil. Keep the plants well watered and in a suitable place, such as a window or greenhouse. Make and keep a record of the growth of the plants, and notice which plant develops best. Make drawings at intervals of several days, and explain the difference in development.

2. Choose three bean seeds, as nearly as possible, equal in weight. Weigh them and record their weight. Cut one of the seeds into small pieces and place in a dish. Put the dish in a hot-air oven and allow the pieces of bean seed to dry. After several hours, take the dish out, allow it to cool, then record the weight. Then replace the dish in the oven and leave for several hours again. Then re-weigh. Continue this until there is no further loss in weight; thus showing that all the water has been driven off. Calculate the difference between the dried bean seed and the original. This will give the amount of water originally present in the seed. Calculate the percentage dry weight of the seed from this. Then transfer the pieces of seed into a weighed crucible and ignite it over a Bunsen burner, to a dull red heat. Continue until only ash is left. Then allow to cool and weigh. Do this again, and continue to do it until there is no further reduction in weight. This then gives the weight of the ash of the seed, and its percentage of the dry weight should be calculated.

Plant one of the other two seeds in sand and the other in soil and allow both to grow in favourable conditions. When the plant in the sand is beginning to show signs of dying off, carefully remove it from the sand, making sure not to break off any of the roots. Then, by means of sheets of blotting paper, remove any extraneous water (this will be found chiefly on the roots). Weigh the plant, then obtain its percentage dry weight and percentage ash as before. Do

the same with the plant in the soil when it begins to show signs of dying off. Tabulate the results in the following manner:

	Weight of Seed	*Weight of Plant*	*Dry Weight*	*Percentage Dry Weight*	*Weight of Ash*	*Percentage Weight of Ash*
Unsown Seed		—				
Plant sown in Sand						
Plant sown in Soil						

Thoroughly study these tabulated results, and write an explanatory account of them.

3. Prepare a culture solution from Knop's prescription. Also prepare the following solutions:

(*a*) Knop's solution, but using calcium sulphate and potassium sulphate instead of the corresponding nitrate; thus omitting nitrogen from the solution.
(*b*) Knop's solution, but omitting potassium phosphate; thus omitting phosphorus.
(*c*) Knop's solution, but using the corresponding sodium salts instead of the potassium salts mentioned; thus omitting potassium.
(*d*) Knop's solution, but substituting sodium nitrate for calcium nitrate; thus omitting calcium.
(*e*) Knop's solution, but substituting sodium sulphate for magnesium sulphate; thus omitting magnesium.
(*f*) Knop's solution, omitting the ferric chloride; thus omitting iron.
(*g*) Knop's solution, but substituting magnesium nitrate for magnesium sulphate; thus omitting sulphur.

Place some Knop's solution in one jar and some of the other solutions (*a*) to (*g*) in other separate jars. Fix some growing bean plants in each jar, by means of a split cork, or cardboard (see Fig. 97). Cover the jars with brown paper to keep the roots of the plants in the dark. Label the jars and place them in a window or greenhouse and keep periodic records of the growth of the plants and any other observed effects, over several weeks.

Fully describe the effects of the absence of these certain elements on the growth, etc., of the plants.

4. Very useful information can be obtained from pot cultures. Fill five pots (about 10 inches in diameter) with sand. Then mix the following artificial manures :

(*a*) Superphosphate, 10 grm.
Potassium sulphate, 2 grm.
Sodium nitrate, 4 grm.
(*b*) The same, omitting the superphosphate.
(*c*) The same, omitting the potassium sulphate.
(*d*) The same, omitting the sodium nitrate.

To Pot 1, adding nothing ; to Pot 2, apply about one-third of (*a*); to Pot 3, one-third of (*b*) ; to Pot 4, one-third of (*c*) ; to Pot 5, one-third of (*d*).

Then sow some mustard seeds in all the pots and place in the open. See they are well watered. After a few days, add another third of the manure mixtures to their respective pots. This is done by mixing the manure with a little sand and sprinkling over the top and watering. A few days later, add the rest.

Make a record of, and if possible photograph, the results.

5. Make a solution of glucose. This substance is obtainable at the chemist's and just a little is required, dissolved in water in a test-tube. Then test for glucose by means of **Fehling's** solution.

This solution is made up in separate parts, Fehling's solution A and Fehling's solution B. A is prepared by dissolving 34·6 grm. of copper sulphate in 500 c.c. of distilled water. B is prepared by dissolving 175 grm. of Rochelle salt and 50 grm. of sodium hydroxide in 500 c.c. of distilled water.

To about half a test-tube full of glucose solution add a few drops of Fehling's solution A. Note the blue coloration. Then add a few drops of Fehling's solution B. Note that the blue coloration now becomes intensified.

Then warm the solution gently over a Bunsen burner. Note that the colour gradually disappears and a bright red precipitate of copper oxide is formed. This indicates the presence of glucose.

6. Test various plant organs for glucose. This is done by extracting some of the juice from the plant organ to be tested. Cut the tissue into fine pieces and then crush the material with a pestle and mortar. If little juice is extracted, add a few c.c. of water and continue to crush. Then perform Fehling's test on the plant extracts obtained.

The following are suggested plant materials for this test : various types of leaves ; carrot, turnip, dandelion, beet, etc. roots ; various stems, potato tubers ; various types of fruit such as apple, pear, plum, tomato, prunes, etc. ; seeds ; and so forth. Make a record of the results.

7. Perform the Fehling's test for sucrose (cane-sugar). Note that there is no reaction to Fehling's solution in this case.

8. To a piece of household starch, add a little iodine solution. Iodine is scarcely soluble in water, so the solution is usually composed of iodine in alcohol or potassium iodide. Note that the iodine on the starch gives a deep blue coloration. This is a well-known reaction of starch.

9. Test for starch in plant organs, by means of the iodine test. Examine certain roots; stems; storage organs such as potato tubers, carrot and parsnip roots, onion and tulip bulbs; apple, orange, banana, fruit, etc. Test as many parts of plants as possible. In all cases, it will be necessary to add the iodine solution to a cut surface.

In the case of green leaves, to note the colour reaction, it is best to remove the chlorophyll first; also, for reasons to be discussed later on, leaves should be gathered immediately after they have been exposed to several hours of daylight. To remove the green colour from a leaf, place it for a few minutes in boiling water. This kills the cells, Then immerse the leaf in alcohol in a test-tube. Place the test-tube in hot water, but remove the flame. The boiling point of alcohol is lower than that of water, so, provided the water is hot enough, the alcohol will boil. Note that the boiling alcohol removes the chlorophyll from the leaf and becomes green in consequence.

When the leaf is white through the loss of its chlorophyll, immerse it in an iodine solution. If starch is present in it, it will assume a deep blue colour. Perform this test on several types of leaves such as those of tulip, *Hydrangea*, onion, elm, hyacinth, etc. Always use thin leaves. Record the names of those leaves which contain starch, and those which do not.

10. Examine some starch grains under the microscope. A good example is that of the potato tuber. Cut a tuber and take a small scraping by means of a knife or scalpel. Enough to cover a pin's head will do. Mount this in water on a slide and examine under the high power of the microscope. By very careful focusing up and down, it will be possible to see the hilum and layers of stratification. Look also for compound grains.

Make drawings of examples of simple and compound grains. Then draw some iodine solution beneath the cover-slip and note the deep blue colour reaction.

Examine and draw other examples of starch grains such as those of the bean seed, rice grain, maize grain, etc. Describe the differences in shape and size.

11. Place some cotton wool in a saucer or dish. Pour some iodine solution over it and note that it turns yellow. Then drain off the extra iodine solution and add some concentrated sulphuric acid. The cotton wool now turns a deep blue colour.

Cotton wool is almost pure cellulose, and this colour reaction is a good test for cellulose.

Make a record of these results, and perform a similar test on a

slice of onion bulb. Explain why a similar reaction, though not so clear, takes place in this case.

12. To the cut surface of a piece of wood, apply a little colourless solution of aniline sulphate or chloride. Note the assumption of a bright yellow colour. This is a well-known colour reaction for wood. Record this result.

Now cut across the stems of certain herbaceous plants, and apply the aniline chloride to the cut surfaces. Look for any evidence of wood and record its position in the stem.

13. Prepare a solution of protein by shaking up the white of an egg in its own volume of water. Then perform the following colour tests for proteins, keeping a careful record of the results :

(a) *Biuret reaction.* Add a little caustic soda to some protein solution in a test-tube. Then add a little copper sulphate solution. A violet colour results.

(b) *Millon's reaction.* To some of the protein solution add some Millon's reagent. The protein is precipitated and turns pink.

Millon's reagent is prepared by dissolving some mercury in twice its weight of concentrated nitric acid. Heat should be applied to accelerate solution, the operation being performed in a fume cupboard. When the reaction has ceased, dilute the solution with twice its volume of distilled water.

(c) *Xanthoproteic reaction.* Add some concentrated nitric acid to the protein solution. A yellow colour results. To this add some ammonia, when the colour is intensified to orange.

Carefully describe these experiments and record the results.

14. Perform the protein colour tests on various cut tissues of plants, such as bean seed, potato tuber, etc. Note and record the position of greatest protein concentration. For example, if the test is applied to the whole cut surface of half a potato tuber, the reaction will be greatest just beneath the skin.

15. Using a piece of animal fat, perform the following tests, recording the results :

(a) The fat makes a translucent mark on paper.

(b) It is not soluble in water, but is soluble in ether, petrol and acetone.

(c) If a little solution of osmic acid be applied to it, a black coloration results.

16. Apply the osmic acid test to the cut surface of the castor-oil seed. Note the presence of the oil.

Note.—The foregoing tests for carbohydrates, proteins and fats should be performed on as many types of plant tissue as time will permit.

Then similar tests should be applied to various familiar plant articles of diet, and those types of food-stuffs detected and those proved absent should be recorded. A good example is ordinary flour.

It must be realised that these tests are really very rough ones. More delicate tests would involve much more time and labour than could be spared. Therefore, it will be necessary sometimes to carry out the tests several times, when they are negative, in order to make sure that that food being tested really is absent.

Field Work

Useful tests for manures can be carried out by applying those suggested for Experiment 4, in various plots in the garden. Unmanured plots and plots with field manure and various mixtures of artificial manures (all carefully labelled) could be cultivated, using the same type of plant on all plots.

A visit to any agricultural or horticultural experimental station within reach would be well worth while. A courteous application to the director of such a station would not meet with a refusal, so long as one is prepared to conform to certain necessary rules. If a party pays such a visit, no doubt guides would be provided, who would add greatly to the interest and value of the visit.

CHAPTER VII

ABSORPTION OF MATERIALS BY THE LIVING CELL

THE structure of a cell, both from the physical and chemical points of view, is very complicated. It may be said that the cell is a veritable chemical laboratory containing, besides a good supply of water, many chemical substances both organic and inorganic, namely, carbohydrates, proteins, fats, mineral salts, etc.

The Cell as a busy Laboratory

This opens up the question: how do all the substances of which the cell is composed get into it? In most cases *all substances enter the cell in the liquid condition*; never as a gas or a solid. They are either in the liquid state themselves or are in solution, usually in water. This gives rise to the question: why is it solids are present in cells, and how do cells give off and absorb gases? For example, there are solid starch grains in many plant cells. It might be suggested that the starch enters in the liquid condition and then becomes transformed into the solid state once it has entered the cell. But this cannot be the case, for starch never exists as a liquid. Then it might be suggested that the starch enters dissolved in water. But this is not so, for starch is insoluble in water. So there can only be one other suggestion, and that is that the starch does not enter as starch at all. It is some other substance which, after entering the cell, becomes built up chemically into starch. This is the case, and therefore various chemical reactions must take place within the cell.

There are hundreds of such reactions taking place. Chemical substances are being built up and others are being broken down into simpler substances. The living cell is like a very busy chemical laboratory, and it is these chemical reactions which

chiefly constitute the living processes of a plant and, indeed, of an animal.

Pressure and Permeability

Many substances will take up water, some very vigorously indeed. For example, concentrated sulphuric acid is used in desiccators because it will absorb a great deal of water, even when the latter is present as water vapour.

Whatever mechanism is used for forcing water into the absorbing substance, there must be some pressure behind it. This pressure, which, of course, varies considerably, is called **suction pressure.** Again, it is easy to conceive that if two absorbing substances are brought into contact with each other, then the one with the greater suction pressure will absorb water from the one with the less, until each contains the same relative amount of water : that is, until there is an *equilibrium* between them.

Now, since cells obviously must absorb water, they must exert a suction pressure.

If a solution of some kind be separated from pure water by means of a membrane, one of three things will happen, according to the structure of the separating membrane. If the membrane be perforated, the solution will pass through easily. The membrane is therefore said to be **permeable.** On the other hand, if the membrane is not perforated at all, like, for example, a sheet of glass, then the solution is completely separated from the water and cannot pass through the membrane, which is therefore said to be **impermeable.** There are membranes, however, which will allow the solvent to pass through, but not the substance dissolved in it (the solute). Such membranes are said to be **semi-permeable.** Parchment paper, for example, is semi-permeable to a sugar solution in that it will allow the water (solvent) to pass through it, but not the dissolved sugar (solute).

Therefore, there must be a pressure set up which forces the water through such a membrane. If a solution of cane-sugar be separated from pure water by a parchment or sausage paper membrane, the water will be forced through the membrane from the pure water side into the cane-sugar side.

This process is well illustrated by a simple experiment

(Fig. 110). Through a bored rubber stopper fit a piece of comparatively wide glass tubing tightly. Then fix another stopper into one end of a cylinder of sausage paper (a good semi-permeable membrane) and ensure no leakage by binding it with strong wire. Fill the sausage paper with a strong sugar solution; then fix the first rubber stopper to which the glass tube is attached, in the other end of the sausage paper. Bind this with wire also. Then immerse, as shown in the diagram, in a vessel of water. Mark, with a piece of adhesive paper, the position of the sugar solution in the tube. After a few hours, the solution will have passed some distance up the tube, thus showing that water has passed from the vessel into the cane-sugar solution. If the solutions are reversed, then the level inside the glass tube will, of course, drop.

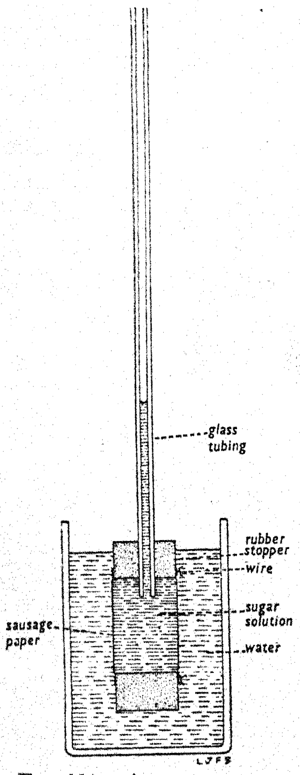


FIG. 110. APPARATUS FOR DEMONSTRATING OSMOSIS.

The pressure responsible for such a passage of water is called **osmotic pressure,** and the process is referred to as **osmosis.** If two cane-sugar solutions be separated by a semi-permeable membrane the water will pass from the lower concentration to the higher, and will continue to do so until the concentrations are equal on both sides of the membrane. That is, *osmosis aims at establishing an equilibrium in concentration on both sides of the membrane.*

The cause of osmotic pressure is still uncertain. Just like other forms of pressure, however, it can be counteracted by any other pressures acting in the opposite direction. For example, if

a sucrose solution be placed inside a semi-permeable membrane and immersed in pure water, as shown in Fig. 111, then a certain weight placed on the surface of the solution, the entry of water by osmosis could be prevented and the smallest possible weight to prevent any entry of water would be that which exerts a downward pressure equal to the osmotic pressure tending to force water inwards.

In the case of a 1 per cent. solution of sucrose this is equivalent to a weight of $10\frac{1}{2}$ lb. per square inch of the surface of the solution, as illustrated in Fig. 111.

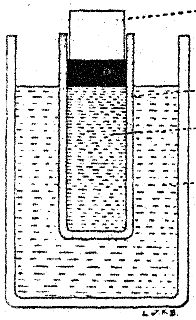


FIG. 111. DIAGRAMMATIC REPRESENTATION OF THE PRESSURE DUE TO OSMOSIS.

The weight is just sufficient to prevent water passing through the membrane into the inside vessel.

The skin of a pig's bladder also forms an excellent semi-permeable membrane. If, therefore, a pig's bladder were filled with a solution of sugar and then immersed in water, the water would pass into the bladder by osmosis. The result would be that the bladder would swell and, since it is elastic, it would become distended. Now, when elastic bodies are stretched, it is well known that, owing to the cohesion of the particles (that is, the attractive force tending to keep the particles of the elastic material together), there is a tendency to resist further stretching, and the more such bodies are stretched the greater does this resistance become. Therefore, as the bladder becomes more and more distended, the more and more does the membrane of the bladder resist this stretching effect. It follows from this that the elastic tension, by resisting the stretching of the membrane, is also resisting the entry of water into the bladder, since it is the latter which is causing the stretching. In other words, while osmosis is tending to force water *into* the bladder, the elastic tension of the membrane is tending to force water *out of* the bladder.

This can be well illustrated in the pumping up of a bicycle tyre.

Here, the water is represented by air. The pressure required to force air into the tyre by means of the pump represents the osmotic pressure. As the air passes into the tyre, it forces the tyre to swell, but the elastic properties of the rubber tyre make it resist this swelling. The more the tyre swells, the more does it resist swelling, and that is why the more a tyre is pumped up, the harder it becomes to pump. The pump is forcing air in, but the swollen tyre is trying to force air out again. It does not succeed in forcing the air out, of course, for there is no passage outwards for the air.

That such a pressure exists is clearly demonstrated if the tyre is punctured; for as soon as the air is supplied with an outward passage, it is forced out. The puncture also shows that the more a tyre is swollen, the greater is its outward pressure, for the harder a tyre is pumped up, the greater is the rush of air when there is a puncture. This is very similar to what is going on in the case of the pig's bladder. Osmotic pressure forces water in; the stretching wall of membrane is trying to press water out. This outward pressure is called **wall pressure**, and therefore, in the case of the bladder, the suction pressure, SP, is equal to osmotic pressure, OP, minus wall pressure, WP. Better still, it can be expressed as an equation:

$$SP = OP - WP.$$

Now, consider the bladder containing the solution of sugar, immersed, not in pure water, but in another sugar solution. If the concentration of sugar inside the bladder is the same as the concentration outside, there will be no passage of water, since osmosis tends towards an equilibrium of concentration and that equilibrium is already established. If, however, the solution outside is stronger, then osmosis will take place towards the outside, with the result that the bladder will lose water. On the other hand, if the solution outside is weaker, then osmosis will take place inwards and the bladder will absorb water, but not at such a great rate as it would if immersed in pure water.

In this case, there is another force acting; that is, the osmotic pressure of the sugar solution on the outside. If the osmotic pressure of the solution inside the bladder be represented by OP_1 and the osmotic pressure of the less-concentrated solu-

tion outside by OP_2, then OP_1 is greater than OP_2, and the suction pressure which forces water into the bladder now can be represented by the equation:

$$SP = OP_1 - (WP + OP_2).$$

In its relation to water, the living plant cell is very similar to the bladder containing the sugar solution. There is one great difference, however. The mechanism depends on elasticity and semi-permeability, and both characteristics are found in the one structure, in the case of the bladder, that is, the bladder membrane. In the case of the cell, the cell-wall is elastic, but quite permeable. Therefore it supplies the necessary elasticity to give the negative wall pressure, but not the semi-permeability to give the osmotic pressure. The semi-permeable membrane is supplied by the protoplasm itself.

The protoplasm of the cell acts as a semi-permeable membrane. It lies against the cell-wall, as we have already seen. The osmotic solution is found in the cell-sap which is present in the vacuole.

Thus, if the cell be immersed in water, it will absorb water, very similar to the way in which the bladder does. This is exactly how it happens in Nature so long as the cell is immersed in pure water or in a solution of a concentration lower than that of the cell-sap. Also, if two cells lying side by side have cell-saps of different concentration, water will pass from the cell of lower concentration to the cell of higher. This is the mechanism whereby water passes from one cell to another.

The tremendous pressure set up by suction pressure in plant cells can be imagined from the behaviour of stored wheat, which becomes accidentally drenched with water. Wheat stored in the holds of ships has been known to burst the sides of the vessels, when water has penetrated into it. A few years ago a granary at Leith, packed with stored wheat, caught fire. The water from the hoses got into the wheat. The cells of the grains absorbed it by suction pressure, with the result that the wheat became so swollen that it burst the walls of the granary.

Our present-day knowledge of osmosis with relation to living cells is due very much to the researches of **Dr. F. F. Blackman, Professor H. H. Dixon** and **Professor S. C. Brooks.**

Turgidity and Plasmolysis

If a cell be immersed in pure water, it will swell, within the limits of the elasticity of the cell-wall. Now, what would happen if the cell were immersed in a solution of a concentration higher than that of the cell-sap ? By the previous reasoning, it is quite clear that the water of the cell-sap would pass *out of* the cell and, instead of swelling, the cell would shrink. This is exactly what does happen. Of course, the vacuole gets smaller and the whole cell, including its protoplasm, shrinks, but the cell-wall, being more or less solid, cannot shrink so much, so the cell proper tears away from the cell-wall ; consequently a space containing some of the solution of immersion is left between the shrunken cell and its cell-wall. In this condition, the cell is said to be **plasmolysed**, and this process of shrinkage is called **plasmolysis**. Plasmolysis can easily be seen under the microscope if cells, such as those of the beetroot, which contain a coloured cell-sap, are used and immersed in a rather highly concentrated solution of salt or sugar. Directions for this are given in the practical work (Fig. 112).

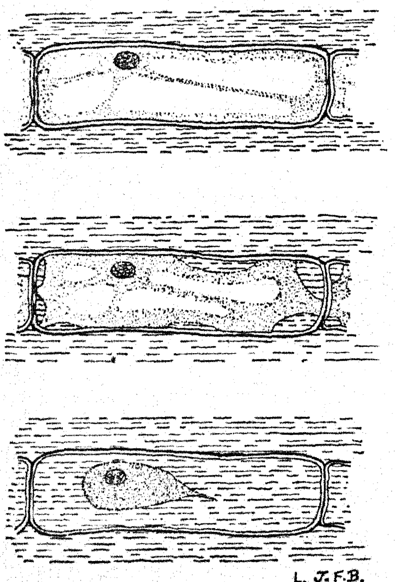


FIG. 112. PLASMOLYSIS IN A CELL.

The top figure represents the cell just as it has been immersed in a strong solution of cane-sugar. Note that the cell is pressed firmly against its surrounding cell-wall. The next figure represents the cell a few minutes afterwards. Plasmolysis has commenced, the cell is breaking away from the wall (the spaces between becoming filled with sugar solution), and the vacuoles are smaller. The lower figure represents complete plasmolysis. Note here the disappearance of the vacuoles.

If such cells are not kept too long in the plasmolysed condition, it is conceivable that they will recover their normal condition if re-

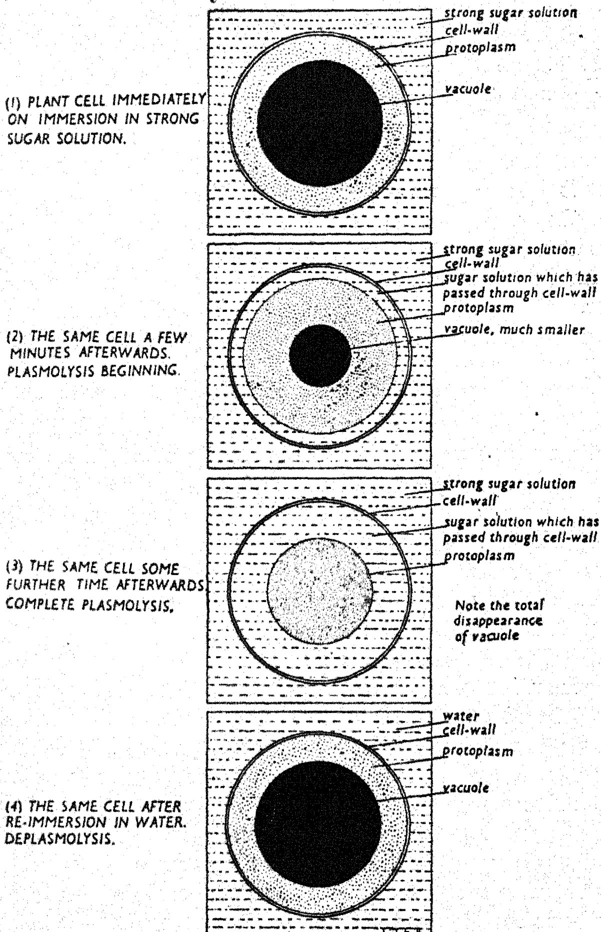


FIG. 113. DIAGRAMMATIC REPRESENTATION OF PLASMOLYSIS AND DEPLASMOLYSIS.

placed in pure water. This actually does happen and the process of recovery from plasmolysis is called **deplasmolysis** (Fig. 113).

When cells contain as much water as they possibly can, they are each pressing firmly against their containing cell-walls, thus giving the whole structure a rigid appearance. The cells in this condition are said to be **turgid.** If they then begin to lose water too vigorously, they begin to plasmolyse, lose their turgidity and firmness, and thus the plant wilts. If the cells are left in this condition too long, they will not recover in any circumstances and the plant finally dies. On the other hand, if the cells get a fresh supply of water within a reasonable length of time, they will deplasmolyse, recover their turgidity, and the plant becomes normal and healthy once more.

What has been said of cells with regard to their relations with water, *applies only to living cells.* Dead cells will not absorb water by osmosis, etc., and they will not plasmolyse.

Absorption of Dissolved Substances by the Cell

Having already some idea of the contents of a cell, it is quite clear to us that water is not the only thing that must enter it. Certain other chemical substances diffuse into the cell too. First of all, it is necessary to remember that all substances enter the cell in solution. Obviously they cannot enter by osmosis, for the semi-permeable membrane of the cell, that is, the protoplasm, by virtue of its osmotic properties, would tend to keep out anything dissolved in the water.

Actually, the dissolved substances enter because the cell protoplasm is never *perfectly* semi-permeable. It is permeable to certain dissolved substances. Some dissolved substances, however, can diffuse much better than others can. Also certain parts of the protoplasmic layer can actually select what substances shall pass through and what shall not.

This **selective action** of the protoplasm is very important, for on it depends what shall enter into the vacuole and what shall not, and, after all, there are certain substances which a plant cell must have and there are other substances which the cell definitely must not absorb.

Those parts of the protoplasmic layer which have this selective power are the layer on the very outside of the protoplasm, that is, the layer of the protoplasm touching the cell-wall, and the

innermost layer which lines the vacuole. These selective layers are called **plasma membranes.** Much work on the plasma membrane of plant cells has been done by **Professor G. Haberlandt.**

It therefore follows from this that if a plant cell be immersed in a solution of several substances, all in equal concentrations, all the substances will not diffuse into the cell in the same, that is, equal, proportions. The rate of diffusion depends on the selective action of the plasma membranes. Such substances as the plant requires will enter easily and those that the plant does not require will enter with great difficulty, or perhaps not at all. We have already seen that relatively much more iodine salts than sodium salts pass into the cells of the brown seaweeds from the surrounding sea-water. This is clearly because the plasma membranes select relatively more of the iodine than the sodium.

Cell permeability has received the attention of many famous plant and animal physiologists, including **Professor J. Loeb, Professor Hugo de Vries, Dr. W. J. V. Osterhout** and **Professor W. Stiles.**

PRACTICAL WORK

1. Demonstrate the phenomenon of osmosis. This can be done in several ways; but a very good method is that already described and illustrated in Fig. 110.

When setting up this apparatus, make sure that the sausage paper is tight around the two rubber stoppers. This can be done by means of copper wire or string. If the paper is not fixed tightly, the solution will leak out.

Make a labelled drawing of the apparatus. Mark by means of a piece of adhesive paper the level of the solution in the tube, then mark in a similar way the level regularly after every twenty-four hours.

Fully describe the experiment and the results, explaining especially why the rate at which the solution rises in the tube gradually decreases.

2. It has already been shown that water can pass from cell to cell in a plant tissue, by means of suction pressure, provided that the dissolved substances in the vacuoles are at the right concentration. This can be shown in a very convincing manner.

Prepare a 'thimble' of plant tissue. That of a potato tuber forms excellent material. Choose a large tuber and pare it roughly

into the shape of a cone. Then with a sharp penknife hollow it out. Half fill this 'thimble' with some 10 per cent. solution of cane-sugar, then, by means of a large needle, suspend it in a vessel of pure water (Fig. 114).

Note that after a time the solution inside the 'thimble' shows signs of rising, and continues to do so slowly. Fully describe this, and explain the results.

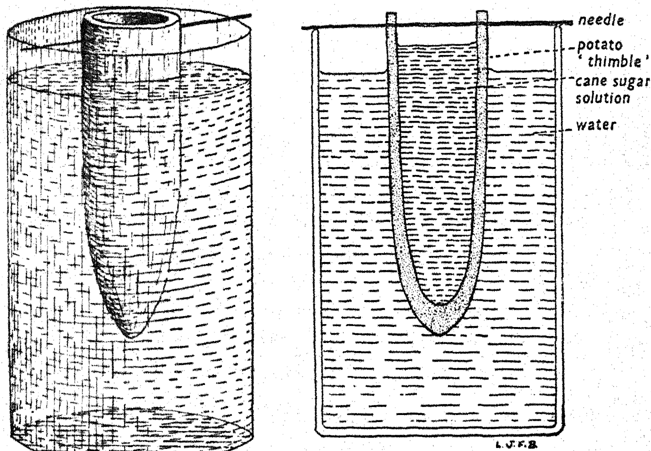


FIG. 114. DEMONSTRATION OF THE PASSAGE OF WATER THROUGH PLANT TISSUE BY MEANS OF SUCTION PRESSURE.

3. The pressure set up by osmosis is easily demonstrated in the case of a strong solution of cane-sugar or common salt. Fill a large basin with some of the solution to be used, then immerse in the solution a glass cylinder or a wide glass tube sealed at one end. Across the mouth tie a piece of the membrane of a pig's bladder (a good semi-permeable membrane). Fix this by means of string or wire. All this must be done under the solution in the basin, to prevent any air bubbles from entering.

Remove the cylinder containing the solution and thoroughly wash it under the tap, to remove all traces of solution on the outside. Then immerse it completely under water and leave for a few hours.

By this time, the solution inside the cylinder will be exerting a pressure on the membrane, causing it to stretch outwards (see Fig. 115). Fully explain this.

4. Cut some slices, about 3 mm. thick, from a beetroot. By gently bending them between the fingers, notice their comparative

firmness. This is due to the cells being full of water and therefore turgid. Then place the slices in a 10 per cent. solution of cane-sugar and leave for about half an hour. Note now that the slices have become very flabby. Replace in pure water and leave for half an hour, and then note that they have regained their firm texture. Fully describe these observations and explain them.

5. By means of a sharp razor, cut some microscopically thin sections of beetroot. Mount them in water and draw one or two of the cells, under the high power. Note especially the vacuoles containing a red cell-sap. Now, by means of a small piece of blotting paper placed at the edge of the cover slip, draw some 10 per cent. sugar solution underneath it. This will cause the cells to plasmolyse. Examine and draw various stages of plasmolysis. Then irrigate the sections with water and look for deplasmolysis.

6. The same experiment can be done with whole leaves of Canadian pondweed (*Elodea canadensis*). Mount a complete leaf in water on a slide and draw one or two of the cells, under the high power. Note especially the small green granules (chloroplasts) which contain the chlorophyll. Then irrigate the leaf with a strong solution of sugar or salt. The green chloroplasts help one to see plasmolysis taking place more easily.

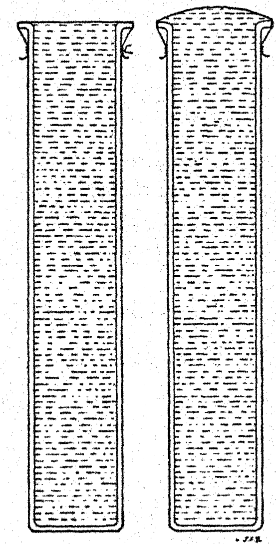


FIG. 115. METHOD OF DEMONSTRATING PRESSURE PRODUCED BY OSMOSIS.

The tubes contain sugar solution and are then sealed with pig's bladder membrane. On the left, a tube before immersion in water; on the right, after immersion. Note, in the latter, the distended membrane.

Now place a small sprig of *Elodea* in boiling water for a few minutes. This kills the cells. Then mount one of the leaves and treat it as before. Note that plasmolysis does not occur in this case. This shows that only living cells possess semi-permeable membranes and are therefore able to absorb water by osmosis.

CHAPTER VIII

THE ROOT

THE normal root of the plant has two main functions and a subsidiary one. They are:

(1) To act as an anchor for the plant, in order that it may remain firmly established in the soil;
(2) To absorb water and dissolved mineral salts from the soil, for the nutrition of the plant;
(3) To store manufactured food-stuffs.

The third function is subsidiary, for in many cases food is not stored by the root at all.

Anchorage of the Plant

It can be clearly seen how efficient the root is as an organ of anchorage.

In the case of tap roots, the long, firm main root grows deeply into the soil, forming a splendid anchorage. How tenaciously the tap root holds to the surrounding soil is easily demonstrated in the case of several well-known plants possessing tap roots. For example, the parsnip, with its long, tapering tap root, is very difficult to extract from the soil. This root resistance, of course, is precisely what the plant needs. The root has to resist, not so much pressure on its sides, as the exposed shoot obviously has, but rather has it to resist any pulling strain. If, for example, a high wind is tending to blow the plant over, or an animal is trying to pull at the plant, in either case this acts on the root as a pulling force.

The parsnip (and another good example is the dandelion, which is such a common weed on lawns) can resist this pulling force to such an extent that, rather than give way and allow the whole plant to be completely extracted from the soil, it will

break, either near the base of the shoot or part of the way down the root. It is necessary to dig the plant up and remove the soil particles to which the root is tenaciously clinging, in order to get the root completely out of the soil.

This firm fixture of the roots in the soil also explains why, when trees are exposed to very high wind pressure, such as we get in a gale, although they sometimes cannot withstand such abnormal pressure and are blown down, yet very little of the roots come up when the tree is 'uprooted.' They tear away instead.

The amount of space that the roots take up in the soil is sometimes very surprising, especially in the case of fibrous root systems. When a plant is simply pulled out of the soil, the amount of root that comes away with it is usually only a small fraction of the whole amount. The majority of the ends of the branch roots remain in the soil. Careful digging around the plant and final washing away of the soil from the roots is necessary in order to get a real idea of the amount of root attached to a plant. In the case of an oak tree, for example, the roots penetrate many feet into the soil; very often as far down as the tree is high if the soil is soft. If, on the other hand, the soil is very rocky, the roots spread

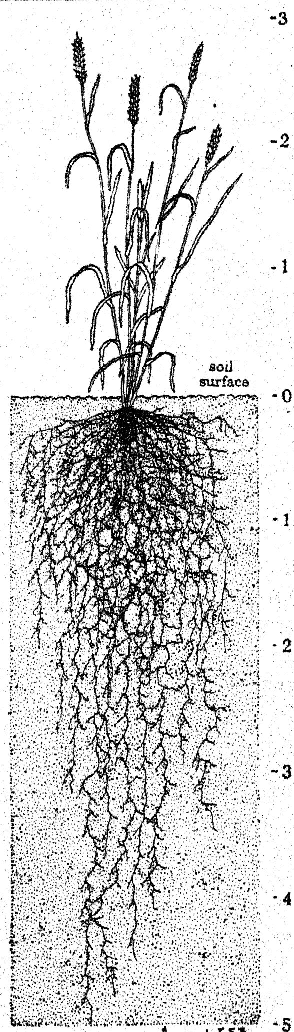


FIG. 116. A COMPLETE WHEAT PLANT, SHOWING THE LARGE, FIBROUS ROOT SYSTEM. The numbers indicate feet.

beneath the soil to an area much in excess of the area covered by the spreading branches. That gives some idea of the amount of root attached to the tree. The roots of the wheat plant usually penetrate to a depth of 5 feet and sometimes even further (Fig. 116).

Protection of the Root

It is clear that the roots of a plant gradually increase in length; and a very important question therefore is: how does this growth take place?

It has already been seen that the flowering plant is composed of thousands of small cells. Many of these cells go to form the root. Growth takes place not only by the enlargement of each individual cell, but also by the formation of new cells; for the individual cell is limited in growth (see Chap. XXI).

The formation of new cells involve many intricate processes which cannot be considered now. Fundamentally, the formation of new cells takes place by the division of cells which already exist. A single cell divides into two. First the nucleus divides to form two nuclei, then the cytoplasm divides itself into two portions, one portion surrounding each of the two new nuclei, then a new cell-wall is formed through the middle of the cell, dividing the two protoplasmic portions. Thus two new **daughter cells** are formed, each of which finally grows to the size of the original **mother cell.** Thus, the cell volume is increased two-fold.

Only very young parenchymatous cells which contain no vacuoles are capable of division. Such cells are said to be **meristematic.** It therefore follows that not all the cells of a plant are capable of division, for only a few are young and parenchymatous. Meristematic cells are often found congregated together in groups, thus forming a **meristematic tissue or meristem.**

The obvious place for the meristem in the root, which grows chiefly in length, is at the very tip. Actually, however, this is not the case, for the meristem of the root is just behind the tip. This can easily be explained. If the meristem were at the tip, it would soon become worn away owing to the root, during its passage of growth through the soil, rubbing against the hard

soil particles. If the meristem were worn away, of course, growth in length could not possibly continue.

Since the root meristem is just *behind* the tip, it is able to produce new cells by division both below and above it. The cells produced above go to form additional root tissue, whereas that below it forms the true tip of the root. These cells which form the true tip of the root are called the **root cap**, and are never modified beyond the parenchymatous condition.

The cells of the root cap are, of course, exposed to the soil. They do, however, form a splendid protection for the young meristem. They must necessarily be worn away as the root pushes its way through the soil, but that does not matter very much, for as the cells are worn away from the root cap by the soil particles, new cells are added from behind, by the meristem. Therefore, as quickly as the root cap is worn away, just as quickly is it replaced (Fig. 117).

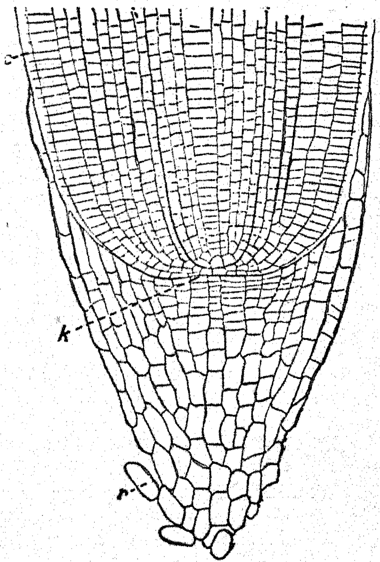


FIG. 117. LONGITUDINAL SECTION THROUGH A TIP OF A ROOT OF THE BARLEY.
k, growing point; *r*, a cell of the root cap; *c*, piliferous layer ($\times 150$).
(*After Strasburger.*)

Absorption of Water and Mineral Salts

By far the most important function of the root is the absorption of certain raw food materials, namely, water and mineral salts from the soil.

A close examination of the soil in which the root grows shows it to be composed of fine particles of rock. The particles are of various shapes, and, therefore, though they are closely packed together, there are many spaces between them. In these spaces air is present. This is absolutely essential to the plant, for the

root must have air as well as water (see Chap XIII). If the spaces are completely filled with water, the soil is said to be **water-logged.** This state of affairs does happen sometimes, and if the soil remains in the water-logged condition too long, the majority of plants growing in it die.

In a well aerated soil, the water itself forms a film around each soil particle. To get at this water film, therefore, the root must be pressed very closely to the soil particles. The purely cylin-

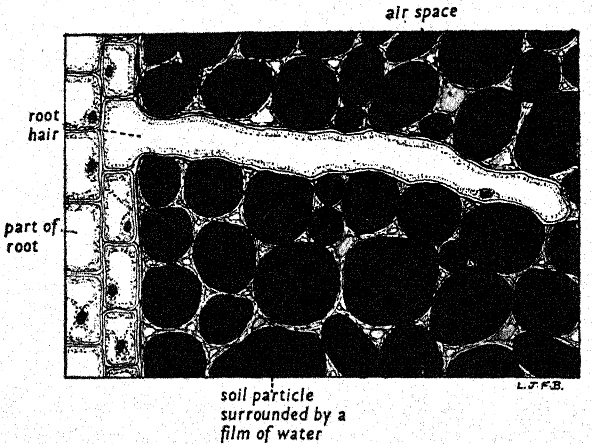


FIG. 118. PART OF A LONGITUDINAL SECTION THROUGH A ROOT, PASSING THROUGH A ROOT HAIR, BENEATH THE SOIL.
Note how closely the hair adheres to the soil particles.

drical portion of the root obviously cannot do this to any great extent owing to its shape. But the long thin root hairs which are found some distance behind the tip can, by taking up a vermiform shape. This is seen in Fig. 118.

That the root hairs press tenaciously against the soil particles can be well demonstrated by growing some cress seedlings in soil. When they have attained a height of about half an inch, gently lift them out of the soil and wash the root under running water. The water will wash the clinging soil particles away from the root, except in the region of the root hairs.

Since, therefore, the root hairs are in direct contact with the

water films in the soil, it is chiefly through these hairs that the soil water, together with its dissolved mineral salts, passes into the root. Each root hair is composed of one long parenchymatous cell, with a very thin cellulose cell-wall, a thin lining layer of protoplasm, and a very large vacuole. Here we have a cell surrounded by water and, therefore, by suction pressure, as explained in Chap. VII, the water passes into it. Thus the water passes into the root.

But, of course, the water has to pass from the root hairs right into the root proper and thence up to the shoot. This involves many other processes, some of which can be considered now, but the others must be left for further consideration (Chap. XII).

Internal Structure of the Root

The structures which are responsible for conveying the water together with its dissolved substances from the root up to the shoot are the pipe-like elements called vessels. These are found in the middle of the root as shown in Fig. 119. Here the vessels are grouped together to form a tissue called **xylem**. The xylem, as is seen in Fig. 120, is embedded in a tissue of parenchymatous cells.

Now, the root is a living part of the plant and therefore must have food, so it is clear that although there is a passage of water, etc., up through the root (via the vessels), there must also be a downward passage of water containing dissolved food-stuffs to supply the root. The elements used in the conveyance of dissolved food-stuffs are the sieve tubes, and, therefore, there must be some sieve tubes present in the root. The xylem is arranged in a more or less star-shaped pattern, when seen in transverse section. The vessels at the points of the star are smaller than those at the centre. The smaller ones are actually the first formed, and the larger gradually develop towards the centre. The first-formed xylem elements form what is called the **protoxylem**, and the larger, later-formed elements, **metaxylem**.

Between the points of the xylem star may be seen groups of sieve tubes. Each group forms a tissue called **phloem**, and the phloem, like the xylem, is embedded in a tissue of parenchyma. Note also that the phloem groups never directly abut on the

xylem. There is always a certain amount of parenchyma between. This mass of tissue for conveying water and dissolved salts up to the shoot (xylem), and water and dissolved foods down

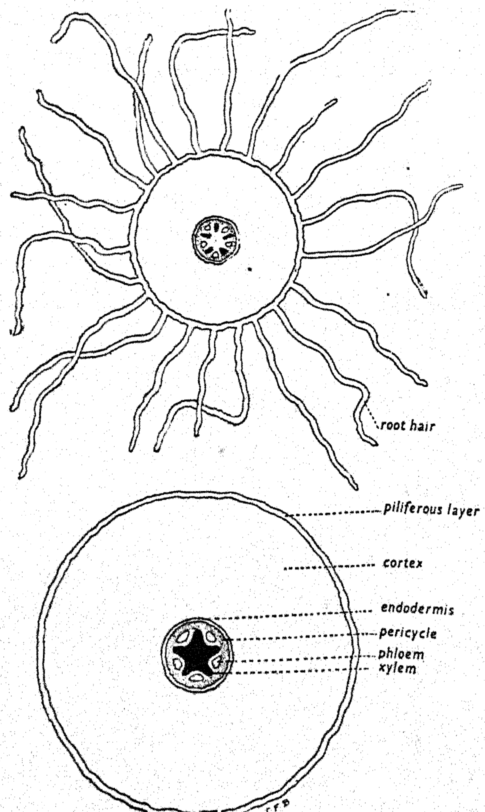


FIG. 119. DIAGRAMMATIC SKETCHES OF THE ROOT IN TRANSVERSE SECTION (LOW POWER).
Above, near the tip, in the root hair region; below, in an older part.

to the root (phloem), together with its matrix of parenchyma, is called the **stele**.

Surrounding the stele is a thin layer of parenchyma called the

pericycle. Surrounding the whole of this collection of tissues is a cylinder of parencyhma called the **cortex.** The innermost layer of the cortex is brick-like in structure. It is called the **endo-**

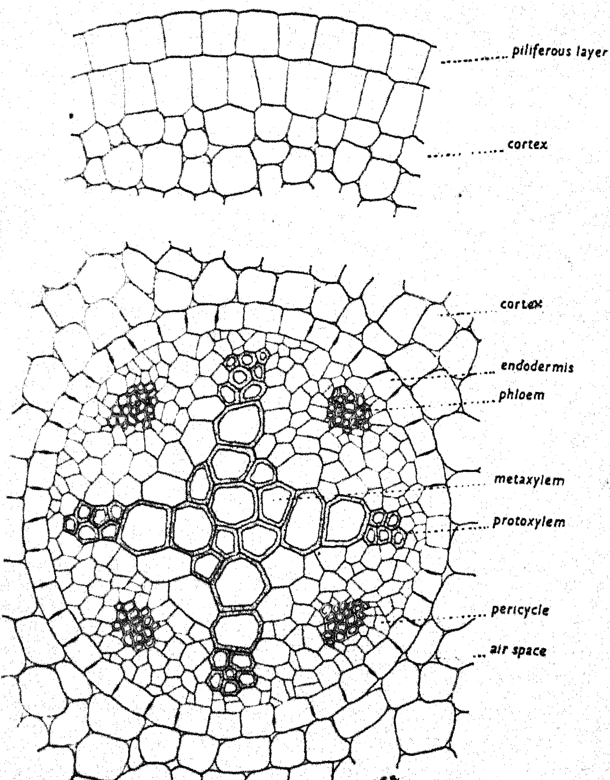


FIG. 120. PORTIONS OF A TRANSVERSE SECTION OF A ROOT UNDER THE HIGH POWER.
Above, the outer tissues; below, the stele.

dermis. The cortex is surrounded by the outermost layer of the root, which is called the **piliferous layer.**

At the region behind the tip of the root, the outer walls of the cells of the piliferous layer grow out to a great distance and produce the root hairs. The layers of cells between the endo-

dermis and the piliferous layer, which comprise the rest of the cortex, are composed of ordinary living parenchyma and have air spaces interspersed among them (Fig. 120).

Passage of Water through the Root

We have already seen how the water gets into the root hairs of the piliferous layer, and we know that the water is conveyed out of the root into the shoot via the vessels of the xylem. Our next consideration therefore is the passage of water across the root from its external hairs to the xylem vessels in the centre.

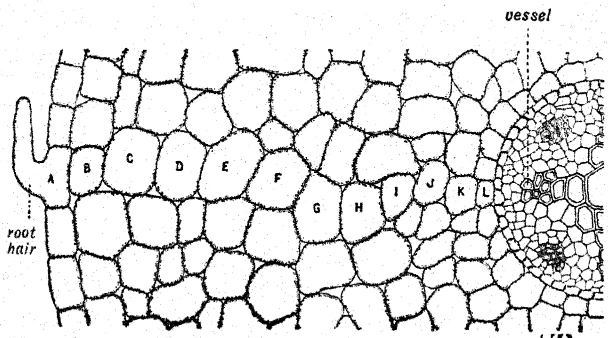


FIG. 121. PART OF A TRANSVERSE SECTION OF A ROOT TO SHOW HOW WATER PASSES FROM THE ROOT HAIR TO THE STELE.

From previous considerations of osmotic and suction pressures, it is known that if two parenchymatous cells are lying side by side and the osmotic concentration in the vacuole of one is higher than that of the other, then water will be drawn from the cell of lower concentration to the cell of higher concentration.

A glance at Fig. 121 will show that this fact underlies the passage of water across the cortex from root hair to xylem vessel. It has been proved that the osmotic pressure of the cells of the cortex increases consistently in the order $A \rightarrow B \rightarrow C \rightarrow D \rightarrow \ldots$. Therefore B will have a higher osmotic concentration than A and will draw water from A. In the same manner C will draw water from D, E from D and so on, until the water reaches the cell L. Thus we can get the absorbed water into the parenchymatous cells surrounding the vessels.

But the same explanation will not help us to understand how the water passes from these cells into the vessels, for vessels are dead elements and therefore contain no protoplasm. Since they contain no protoplasm, they cannot have a semi-permeable membrane. Therefore the entry of water into the vessels cannot be explained by osmosis. The mechanism here is still a mystery.

The next problem is: how does the water get from the vessels up to the shoot, right into the leaves, especially the leaves of a tall tree? Clearly it is forced up, but the forces involved are several and complicated. These will have to be deferred for further consideration in Chap. XII.

However, the root does play a certain part in forcing the water up to the shoot. It exerts a definite pressure upwards of water. This pressure is called **root pressure.** Although root pressure will therefore help to force water up through a plant, it is insufficient in itself. It could not, for example, force water from the roots to the uppermost leaves of an elm tree.

Food Storage in Roots

The third function of some roots is that of food storage (Chap. IV). The food is manufactured in the leaf, and then translocated down through the phloem to the root where it is stored, chiefly in the parenchymatous cells of the cortex.

Roots are also modified sometimes, for other functions such as climbing and gaseous interchange. These modifications were examined in Chap. IV.

Roots and Fungi

One of the most important elements which a plant requires is nitrogen. The normal plant never absorbs the nitrogen from the atmosphere, as it does carbon dioxide. It extracts its nitrogen from the soil. The nitrogen is present in the soil in the form of nitrates, etc.

There are, however, certain plants which have special means of obtaining their nitrogen supply. If the roots of certain heaths, orchids, and many forest trees be examined, they will be seen to

be covered with a colourless, filamentous fungus which ramifies all over the surface of the roots and sometimes actually penetrates them. Since the fungus cannot build up carbon and nitrogen food-stuffs in the way a green plant can, it absorbs certain organic nitrogen and carbon compounds from the plant on which

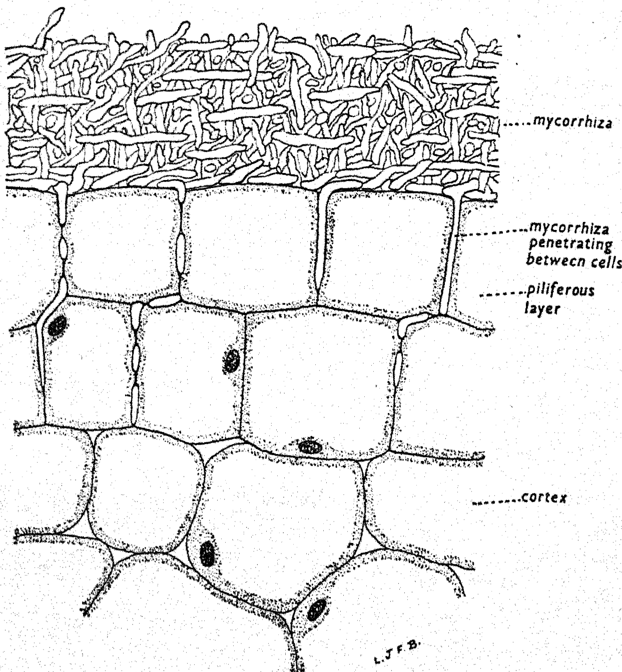


FIG. 122. TRANSVERSE SECTION OF A PART OF A ROOT OF THE SCOTS PINE, SHOWING THE PILIFEROUS LAYER, SURROUNDED BY ECTOTROPHIC MYCORRHIZA. NOTE SOME OF THE FUNGAL HYPHÆ PENETRATING *between* THE CELLS.

it is growing, and also from the decaying dead plant and animal material in the soil around it. This type of fungus is called **mycorrhiza.**

There are two forms of mycorrhiza: (*a*) the ectotrophic, in which the fungus grows only on the surface of the root (Fig. 122), and (*b*) the endotrophic, in which it actually penetrates the cells of

the root (Fig. 123). The mycorrhiza of the pine, spruce and larch is ectotrophic, whereas that of the yew, etc., is endotrophic.

Now since the mycorrhizal fungus absorbs certain organic nitrogen and carbon compounds from the soil, and since it penetrates the roots of its host plant, certain of these compounds must be absorbed by the host plant from the fungus.

The presence of mycorrhizal fungus is sometimes very important, especially to forest trees. The normal plant absorbs nitrogen from the soil in the form of inorganic nitrates. It is to be expected, therefore, that the soil of forest lands would soon

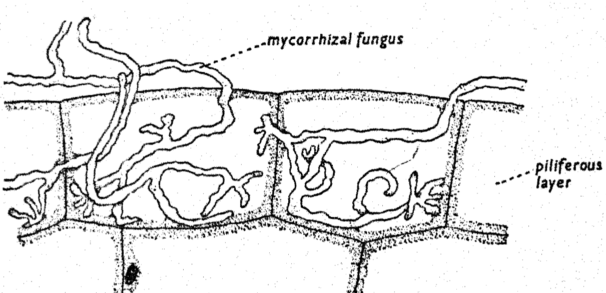


FIG. 123. A FEW CELLS OF THE PILIFEROUS LAYER OF THE BIRD'S-NEST ORCHIS, SHOWING SOME HYPHÆ OF AN ENDOTROPHIC MYCORRHIZA BEGINNING ACTUALLY TO PENETRATE *into* THE CELLS.

become very poor in such inorganic salts, owing to the great demand made upon it by such tremendous plants. At the same time, such a soil would be well supplied with decaying fallen leaves, which would supply plenty of organic matter (humus) to the soil. The surrounding soil would therefore contain much nitrogen in the organic condition ; but the root of the normal plant cannot absorb *organic* materials from the soil. The fungus, on the other hand, can ; and in that capacity is therefore indispensable to many forest trees.

This is the first example we have come across where two different forms of plants are living together, actually joined together. Yet, neither harms the other ; in fact, each does the other good. The flowering plant supplies the mycorrhizal fungus with certain foods, especially carbohydrates, through its root, and the

fungus in its turn obtains nitrogen from the soil humus and passes it on to the root of the flowering plant. Thus both plants live together for mutual benefit. This phenomenon is called **symbiosis.**

Much work on mycorrhizal fungi has been done by **Dr. M. C. Rayner**, who, from studies of certain crop plants, has found that mycorrhizal fungi live on the roots of orange trees, to the mutual advantage of both plants. Such fungi have already been demonstrated on the roots of such plants as the strawberry, sugar-cane and wheat. Thus, it is likely that these fungi will prove to be of the utmost importance to the grower when more has been learned about them.

The Nitrogen Cycle

For centuries it has been known that one way to enrich the soil is to grow certain plants which belong to the family **Leguminosæ**, and certain other families, on it. Some of the best-known plants belonging to the family Leguminosæ which actually enrich the soil with nitrogen compounds, rather than make it poorer, are peas, beans, clover, etc.

For this reason, clover is often cultivated on farm land. It is a crop often used in crop rotation, usually followed in the next season by wheat, which derives great benefit from the soil which has been enriched by the clover of the previous season. Sometimes, especially if the clover turns out to be a poor crop, it is merely cultivated until the end of its growth and then just ploughed into the soil, where, during the winter, it decays, thus giving a splendid natural manure to the soil. More often, however, the crop of clover is harvested; but much addition of nitrogen compounds to the soil has taken place, as we shall see, from the roots of these leguminous plants alone.

Clover is usually cultivated as **fodder** for farm animals. One advantage that this crop has over ordinary hay is that it may be gathered and preserved in the wet condition and not in the dry. The almost heart-breaking effects that bad weather can have during the hay-making season, especially in Great Britain, is well known. The clover crop, however, is not so adversely affected by weather conditions.

The clover is gathered in the fresh condition and stored in a **silo**, which takes the form either of a pit or a tower above ground. The fodder which results from this storage is called **silage**. Other crops are used for silage in Great Britain, such as pulses and cereals, especially maize; also grass, if the weather conditions are too unsatisfactory for hay-making.

Silage is a wholesome food for all classes of cattle, since they digest it rapidly and keep in a good condition when fed upon it. Sheep also do well on it, though it is not so palatable to them as it is to cattle. Horses eat it readily when it is served in small quantities mixed with chaff. On the other hand, it is not a good diet for pigs.

Clover and other leguminous plants make quite a good silage; but not so good as cereals since, unfortunately, it tends to get rank and sour. Therefore, this crop should be quite mature before harvesting, thus keeping the moisture content of the plants down to a minimum. A mixture of clover and maize makes excellent silage.

It is interesting to note that gorse (furze or whin as it is sometimes called) is used in the south of Ireland, where hay is scarce, for feeding horses in winter. The seed is sown on spare ground and the crop, cut the following year, is passed through an ordinary chaff-cutter before being served. Gorse was used for this purpose much more extensively in Great Britain before root crops formed a winter feed for the farm animals. Gilbert White, the naturalist, in his famous "Natural History of Selborne," wrote, "The sowing of whins for feeding of cattle takes mightily about London just now [1725] . . . this improvement comes from Wales, where it has been practised these hundred years."

Atmospheric Nitrogen and Bacteria

Very often, however, clover is cultivated with no intention of harvesting it for silage. The reason for this is that it definitely enriches the soil by supplying extra nitrates to it. The question is: how does this nitrification of the soil take place, since we know that the green plant cannot absorb nitrogen from the atmosphere?

Towards the end of last century experiments were carried out

to settle this problem. Plants, such as wheat, were grown in soil deficient in nitrates. They were found to become unhealthy, although the atmosphere around them contained a large quantity of nitrogen. On the other hand, clover and other leguminous plants were found to flourish quite well on such soils. It seemed therefore that they could absorb atmospheric nitrogen and build it up into their proteins and protoplasm.

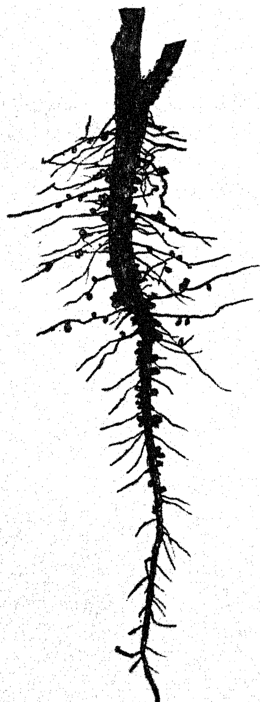


FIG. 124. A ROOT OF THE BROAD BEAN, BEARING ROOT NODULES.
(*After Noll.*)

After much investigation, it was discovered that the clover was able to absorb the nitrogen because it had thousands of cells of a certain bacterium present in the parenchymatous cells of the cortex of its roots.

If the roots of clover or the bean be examined, it will be seen that in places they are swollen to form definite excrescences or **nodules** (Fig. 124). The nodules are really localised swellings of the cortex, and in the parenchymatous cells of these swellings the bacterium lives. This bacterium is called *Bacillus radicicola*. It is a very small (hundreds of times smaller than a normal cell) spherical plant and is present in millions in the soil (Fig. 125). For some reason or other, it will attach itself to the root hairs of the clover plant and, when there is a large number of them, the wall of the root hair becomes soft and finally breaks (Fig. 126). Thus the bacteria enter the root and multiply prolifically in the cells of the cortex. These cells rapidly enlarge to accommodate the thousands of bacteria and they even divide to produce new cells. Thus the nodules are formed (Fig. 127).

Bacillus radicicola has the property of being able to absorb atmospheric nitrogen and build up nitrogen compounds suitable

for absorption by the green plant. The green plant, of course, cannot absorb atmospheric nitrogen.

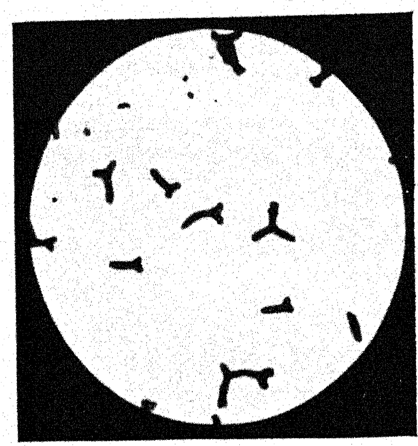


FIG. 125. BACTERIA (*Bacillus radicicola*) FOUND IN THE NODULES OF LEGUMINOUS PLANTS.
(*Photomicrograph, Rothamsted Experimental Station.*)

This absorption of atmospheric nitrogen by the bacterium is referred to as **nitrogen fixation.** Thus, *Bacillus radicicola*, far from being a nuisance to the clover and other plants in which it

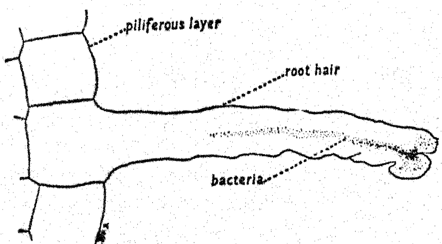


FIG. 126. *Bacillus radicicola* PENETRATING THE ROOT HAIR OF A BROAD BEAN.

thrives, is a great asset. But it demands something in return. It cannot manufacture any carbohydrates by photosynthesis since it contains no chlorophyll, and even if it did, the chlorophyll would be useless since the bacterium is permanently in the

dark. It therefore absorbs its carbohydrate foods from the roots of the flowering plant. Thus, we have another example of symbiosis. The bacterium and the leguminous plant live in symbiotic harmony with each other.

Now it can be seen why clover and other leguminous crops are invaluable in agriculture, even if they are not harvested for

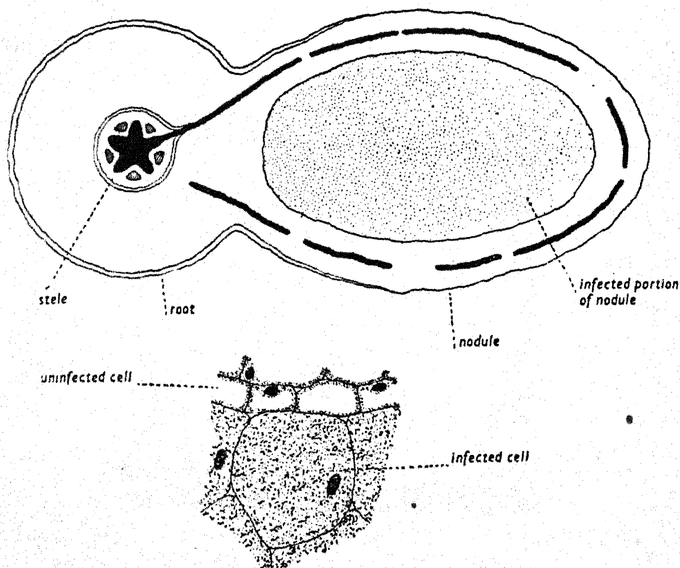


FIG. 127. ABOVE, TRANSVERSE SECTION OF A BROAD BEAN ROOT, PASSING THROUGH A ROOT NODULE. BELOW, A FEW CELLS FROM THE NODULE, ENLARGED.

fodder. The quantity of atmospheric nitrogen fixed by the bacteria in a crop of clover is so great that if the crop is grown on an impoverished soil and then allowed to rot on it or ploughed into it, the soil, from the point of view of nitrate content, is no longer poor.

This enrichment of the soil through nitrogen fixation by the bacteria present in leguminous plants has been known for centuries. It was recognised by the Romans and Greeks and was used by them for the purpose in crop rotation. The fact that it

is due to the fixation activities of the bacterium, *Bacillus radicicola*, was, however, not revealed until after much research towards the end of the nineteenth century.

Bacillus radicicola is not the only means of supplying nitrogen compounds to the soil. These nitrogen compounds are the most important ones to the plant, in the soil, for the other important elements, as will be seen later, are all obtained from the soil, water or the atmosphere. It is clear, therefore, that there must be other methods of enriching the soil with nitrogen. Much

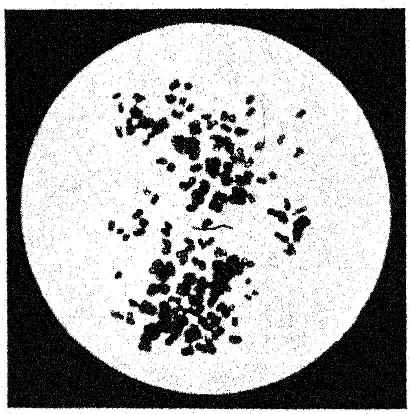


FIG. 128. BACTERIA (*Azotobacter*) FOUND IN ALL FERTILE SOILS. (*Photomicrograph, Rothamsted Experimental Station.*)

nitrogen is added in Nature in the form of humus, as seen in Chap. VI. It is also added by artificial manuring.

But there are other means of fixing atmospheric nitrogen in the soil and thus supplying nitrates, without the aid of plants bearing root nodules. There are certain free-living bacteria present in nearly all soils which can absorb and fix atmospheric nitrogen. One such bacterium is called *Azotobacter* (Fig. 128).

The air which supplies the nitrogen to such bacteria is, of course, present in the spaces between the soil particles.

The flowering plant usually absorbs its nitrogen from the soil *in the form of nitrates*. Now humus seldom contains nitrogen in this form; therefore, the formation of nitrate from humus, first of

all, takes place in the soil in several stages, each stage being dependent upon a definite bacterium. Many nitrogen compounds in the soil are formed chiefly of ammonium salts. These ammonium salts are produced from the decaying humus in the soil. But the plant cannot easily absorb nitrogen in the form of ammonium compounds, which are therefore converted by the

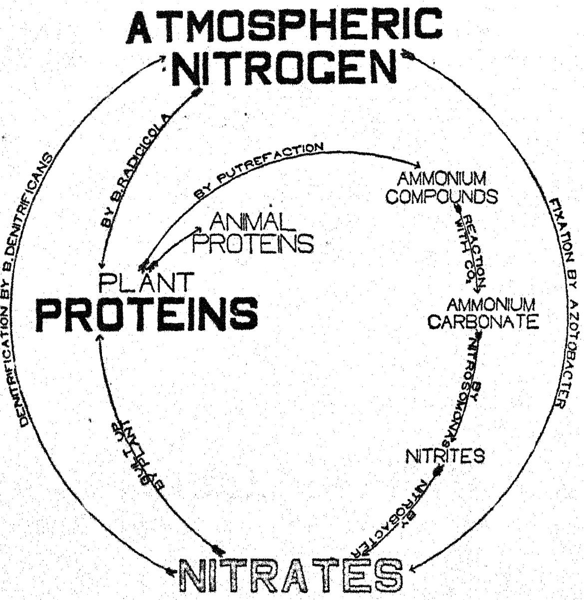


FIG. 129. THE NITROGEN CYCLE.

action of certain bacteria. Some plants, however, can absorb the necessary nitrogen from ammonium compounds.

The first action is purely a chemical one. These ammonium salts react with the carbon dioxide present in the soil to form ammonium carbonate. Then the ammonium carbonate is acted upon by a bacterium called *Nitrosomonas* which converts it into nitrates. Nitrogen in the form of nitrite is still not very suitable for absorption by the roots of most plants. Therefore the nitrite is acted upon by a different bacterium called *Nitrobacter*,

which converts it into nitrate. In this form, the nitrogen is very accessible to the absorbing root. Nitrites, however, are a suitable source of nitrogen to some plants.

The foregoing account of nitrogen fixation gives us some idea of the activities of bacteria. Bacteria are often looked upon as being a menace to both plant and animal life. Of course, it is true that many diseases are caused through bacterial activity, such as typhus, tuberculosis and diphtheria. There are, however, many kinds of bacteria which are harmless, and many which are definitely useful to other living things. Some are even essential. As has just been seen, the nitrogen-fixing bacteria are very useful to the green plant, and it is not exaggerating to say that these bacteria are essential to *all* life on the earth ; for, without them, the supply of available nitrogen in the soil would eventually be used up and no more could be obtained, at any rate in sufficient quantities. Thus, the green plants would finally disappear and, therefore, for reasons already considered (Chap. I), all animals would finally disappear also.

There are certain bacteria which have the opposite effect to the ones so far considered. Instead of building up nitrates from free, atmospheric nitrogen, they do the reverse. Thus, instead of adding available nitrogen to the soil, they release it. Such bacteria are therefore called **denitrifying** bacteria, and the commonest example is *Bacterium denitrificans*.

Thus, in Nature, nitrogen passes through several phases or cycles. The whole phenomenon is often referred to as the **nitrogen cycle.** This cycle is represented in diagrammatic form in Fig. 129.

PRACTICAL WORK

1. By making fully labelled drawings, revise the different types of root systems.

2. Examine and draw an entire young root of the mustard (*Brassica nigra*), which has been cultivated on damp blotting paper (Chap. III, No. 3). By means of a lens, or a low power of the microscope, examine and draw the younger regions enlarged, showing the cylindrical root, the root cap and the root hairs.

3. Prepare a transverse section of a young bean or buttercup root for examination under the microscope.

The root should be placed between two pieces of pith or carrot tissue, in order that the whole may be held easily between the thumb and forefinger. Then dip the material in water in order to moisten it (never cut dry material). For cutting microscope sections, a very sharp razor is required. Dip the blade of the razor in water too. Then cut the sections, holding the material vertically and drawing the razor quickly across it. Aim at cutting the sections as thin as possible, for it is impossible to see the structures under the microscope if they are thick. Cut a large number of sections (about fifty); then wash them into a small dish of water. By means of a camel-hair brush, select the thinnest and mount it in water on a slide and cover with a cover-slip. Irrigate in the usual way with aniline sulphate, which will colour the xylem elements yellow. (Why ?)

Look for: (1) the piliferous layer, with its root hairs; (2) the cortex, composed of (*a*) cortex proper and (*b*) the endodermis; (3) the stele, composed of (*a*) xylem (protoxylem and metaxylem), (*b*) phloem and (*c*) pericycle, all of which are embedded in parenchyma.

Make a low-power drawing of the section, showing the relative positions of the various tissues. When making a low-power sketch like this, *never indicate cells*. Just indicate the various groups of tissue as in Fig. 119.

Then examine the tissues under the high power and make detailed drawings, showing the cellular structure. It is a waste of time to draw the whole section in detail. Select just enough to show some of all the tissues (see Fig. 120), making several separate drawings if necessary.

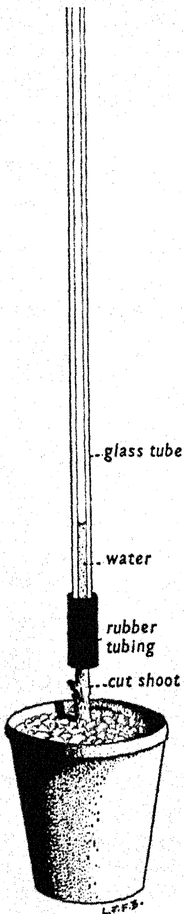


FIG. 130. EXPERIMENT TO DEMONSTRATE ROOT PRESSURE.

5. Demonstrate the presence of root pressure in a plant.

Choose a potted plant, such as *Pelargonium*, with only one main stem. Place the whole under water in a sink so that the level of the water is about three inches above the surface of the soil in the pot. Then by means of a sharp knife sever the

shoot, about two inches up the main stem, and, using a piece of thick rubber (pressure) tubing, fix a glass tube (about 18 inches long) to the cut end of the stem remaining in the pot (Fig. 130). By performing these operations under water, air is prevented from getting into the vessels, and thus blocking the passage of water in them.

Remove the pot from the sink and fix the tube vertically by means of a support. Mark the position of the water-level inside the tube, and mark it regularly for several days.

Draw the apparatus, describe the experiment, and record and discuss the results.

6. Make a large selection of different storage roots and, by the various methods described in Chap. VI, test them for food reserves.

Tabulate the results.

7. Examine the root system of various leguminous plants, such as broad bean and clover, and look for root nodules. Make a drawing of them.

Prepare a transverse section of such a root and notice and draw the swollen, infested cortical tissue forming the nodule. (Specially prepared slides, obtainable from various supply stores, are usually desirable for this, since the bacteria often require special staining to be clearly visible.)

CHAPTER IX

THE STEM

Work of the Stem

THE chief functions of the stem depend upon the fact that it is a part of the shoot. It may be looked upon as the axis upon which the other organs of the shoot are borne. From its terminal and axillary buds, flowers or branch shoots are borne. As lateral appendages to the stem, the leaves develop. Thus in most cases the flowers and the leaves are held up into the air where they can best gain access to the chief things they require for their well-being, that is, warmth and light from the sun and various gases from the atmosphere.

The stem is also the physical connecting link between the shoot and the root. Therefore, all the water and dissolved salts absorbed by the root from the soil, which have to pass up into the shoot where they are used (especially into the leaves), pass up through the stem. Also, the manufactured food-stuffs, which are made chiefly in the leaves, some of which have to be transported to the root, pass down to it, through the stem.

As in the case of the root, the same types of elements are used for this transportation of water, dissolved substances and manufactured foods. In the stem, the xylem and phloem are arranged quite differently from the way in which they are arranged in the root. There, the xylem forms a stellar mass and the phloem is situated between the points of older wood. In the stem, on the other hand, at any rate in the young stem which has not developed any secondary thickening, the xylem is arranged in several definite and separate groups. Closely associated with each group of xylem is a group of phloem. Thus there are several bundles of conducting tissues in the stem. Each bundle is called **a vascular bundle.**

In the common dicotyledonous stem, the vascular bundles are arranged in cylindrical form. Therefore, in transverse section, they form a ring (Fig. 131). The parenchymatous tissue between two adjacent vascular bundles forms what is called a **primary medullary ray.**

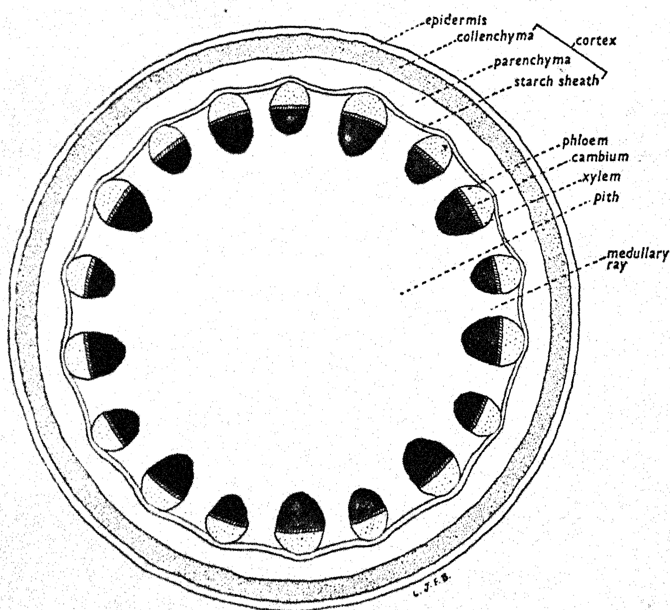


Fig. 131. Diagrammatic Representation of the Transverse Section of a Dicotyledonous Stem.

Examination of a transverse section will show that the stem is composed of three chief parts: the outer single layer of cells, the **epidermis**; a band of tissue composed of parenchymatous cells with large intercellular spaces, the cortex; and a central cylinder or stele composed of vascular bundles separated by primary medullary rays and embedded in parenchyma. Surrounding the central cylinder is a layer or two of parenchymatous cells which form the pericycle. Sometimes the innermost layer of the cortex contains abundant starch grains and is then

referred to as the starch sheath or endodermis and often some of the outer layers of the cortex become thickened for extra protection. The stele is larger, and the cortical band less wide, than in the case of the root.

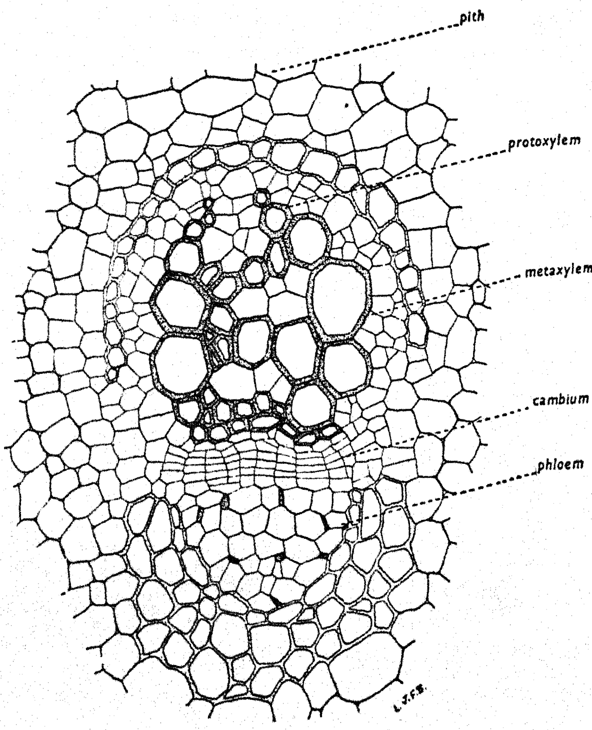


FIG. 132. TRANSVERSE SECTION (HIGH POWER) OF THE VASCULAR BUNDLE OF A DICOTYLEDONOUS STEM.

A more minute examination of the vascular bundle reveals that the small-celled protoxylem is nearer the centre of the stem; thus differing from that in the root (Fig. 132). The later formed xylem (metaxylem) is on the outside. Between the xylem and the phloem is a tissue of small, living, and very active cells collectively called the **cambium**. This is required when the stem begins to become thickened.

Secondary Thickening in the Stem

Secondary thickening depends on the activity of the cambium. During such thickening, a complete cylinder of extra wood and phloem is formed. In the primary, that is, unthickened,

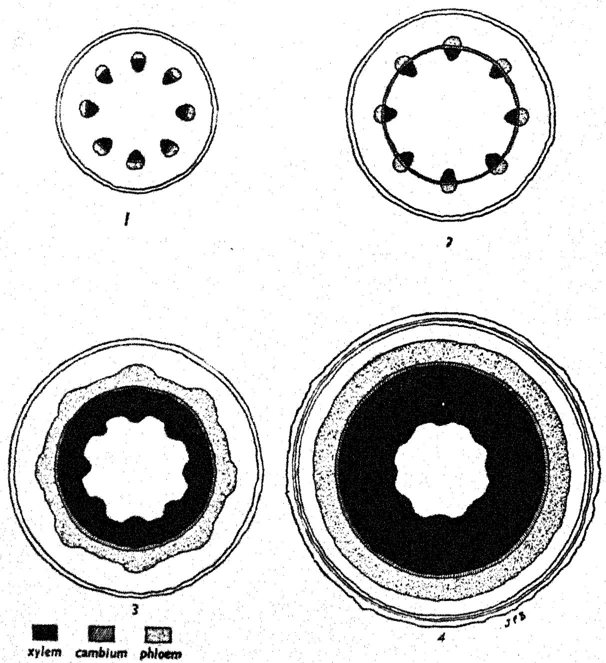


FIG. 133. EARLY STAGES IN THE SECONDARY THICKENING OF A DICOTYLEDONOUS STEM (DIAGRAMMATIC).

stem, the cambium does not form a complete cylinder. The first step, therefore, is the formation of a complete cylinder of cambium.

The original cambium, that is, the cambium between the xylem and the phloem of each vascular bundle, is referred to as **fascicular** cambium. The adjoining cells in the medullary rays, that is, those on the same circumference as seen

in transverse section (Fig. 133), now become modified to form more cambium which is called **interfascicular** cambium. Thus a complete cylinder (ring in section) of cambium is formed.

These cambial cells now actively divide, chiefly towards the centre and vice versa, of the stem. Those new cells produced towards the centre become lignified and form new xylem elements; and those on the outside are modified into phloem elements. Some cells between remain unmodified and persist as cambium, for if all the new cells produced by the division of cambial cells were to become modified, then the cambium would disappear and growth in thickness would perforce cease. Thus the woody cylinder in secondarily thickened stems is produced.

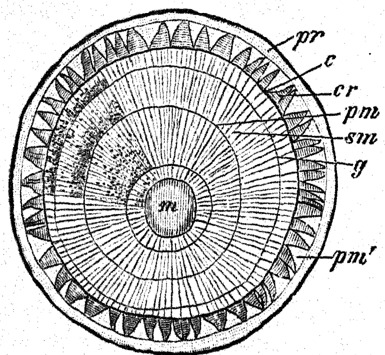


Fig. 134. Transverse Section of the Stem of Lime in its Fourth Year.

pr, cortex; *c*, cambium; *cr*, phloem; *g*, end of third year's growth; *m*, pith; *pm*, primary medullary ray; *pm'*, the ray expanded in the phloem; *sm*, secondary medullary ray.

(*After Schenck.*)

The process of secondary thickening continues from spring to autumn, after which it ceases for that year. The new wood vessels produced, during this growing season, are large in the spring and gradually become smaller towards the end of the season of growth. Thus there is a definite distinction between the small wood vessels of the autumn and the larger vessels of the following spring, giving the annual rings in a section of a thick stem or trunk, as described in Chap. III (see also Fig. 134).

Now all the elements of the wood are hard since they are lignified, and as the woody cylinder gets thicker and thicker through cambial activity, the outer tissues, that is, cambium, phloem, pericycle, cortex and epidermis, are pushed further out. So these outer tissues run a risk of being cut off from a water

supply. To prevent this, certain areas of the cambium, instead of producing new xylem and phloem, produce ordinary living parenchyma. Thus, periodically, throughout the thickened stem, radial passages of parenchyma may be found, which act as paths for a water supply across the stem. These patches of living tissue across the wood are called **secondary medullary rays** (Figs. 134 and 135).

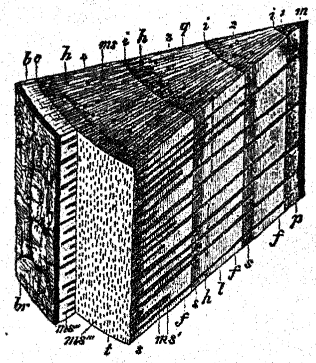


FIG. 135. PART OF A FOUR-YEAR OLD STEM OF PINE.

1, 2, 3, 4, the four annual rings of the wood; *b*, phloem; *br*, bark; *c*, cambium; *f*, spring wood; *i*, junction of wood of two successive years; *m*, pith; *ms*, medullary rays; *s*, autumn wood.

(*After Schenck.*)

In monocotyledonous stems there are many vascular bundles, and they take a haphazard and tortuous route. In transverse section, many are seen, and they are small and arranged irregularly (Fig. 136). It is difficult to conceive of secondary thickening, like that in a dicotyledonous stem, taking place here; and, indeed, it does not. With very few exceptions, the monocotyledonous stem, for example, grasses and cereals, is never secondarily thickened.

Secondary Thickening in the Root

Secondary thickening takes place in dicotyledonous roots; but only in very rare cases of monocotyledonous roots. When secondary thickening is about to commence, the parenchymatous layers immediately outside the protoxylem and inside the phloem become modified to cambium. Then these layers become united by further modification of the parenchyma between, thus, in transverse section, producing a corrugated ring. Then secondary thickening takes place in a manner similar to that of the stem (Fig. 137). Medullary rays are also produced, extra large ones being formed immediately opposite the protoxylem groups.

Cork and Bark

As secondary thickening proceeds in the root and stem, the central cylinder of wood and phloem is enlarging in diameter, thus pushing the surrounding tissues further outwards. If this went on indefinitely and nothing else happened, the outer tissues

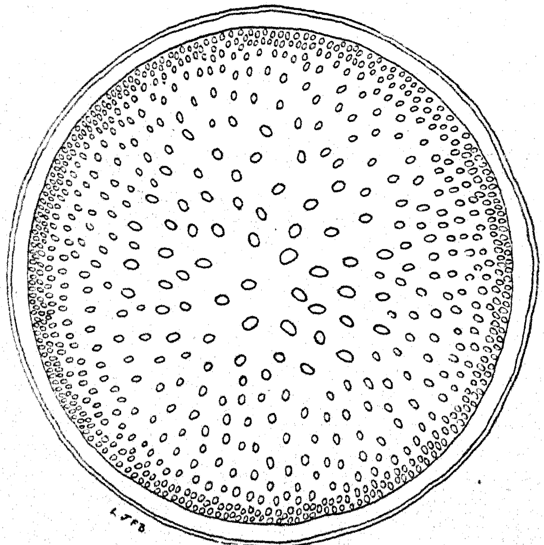


FIG. 136. DIAGRAMMATIC REPRESENTATION OF A TRANSVERSE SECTION OF A MONOCOTYLEDONOUS STEM.
Note the large number of vascular bundles.

would become ruptured. This is prevented by the formation of new cortical cells.

A cylinder of cortical cells—in the case of the stem, just beneath the epidermis (the distance beneath varying with the species) in the root, just outside the central cylinder—form another cambium called the **cork cambium.**

In the stem, this cambium acts like the wood cambium, except that the cells produced by it inwardly develop into the new cortical cells which are required, whereas those produced outwardly become modified into cork. Now this corky layer is

naturally impervious to water, so that all the tissues outside become cut off from a water supply. They therefore wither and

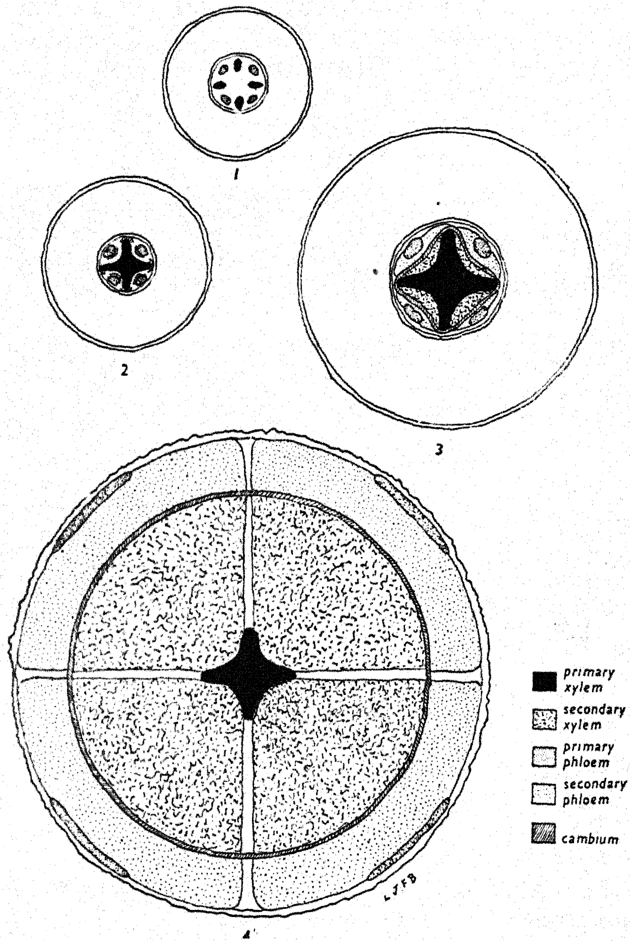


FIG. 137. EARLY STAGES IN THE SECONDARY THICKENING OF A DICOTYLEDONOUS ROOT (DIAGRAMMATIC).

form the bark. The thickness of the bark depends on the original depth of the cork cambium.

In the root, the cork cambium produces only cork. No new cortex is formed. Therefore the secondarily thickened root is composed solely of a woody cylinder, cambium, phloem, cork cambium, cork and bark. The cortex has completely been destroyed to form the bark (Fig. 138).

Creeping and Climbing Stems

The stem usually grows up, seeking air and light. It must, therefore, be of a reasonable firmness and strength. But there are exceptions to this, varying according to the habit of the plant to which they belong.

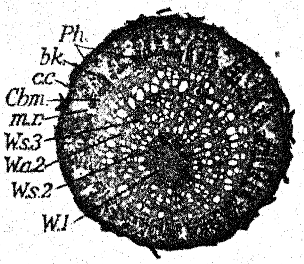


FIG. 138. PHOTOMICROGRAPH OF A TRANSVERSE SECTION OF A THREE-YEAR OLD ROOT OF LIME.

*W.*1, first year's wood; *W.s.*2, spring wood of second year; *W.a.*2, autumn wood of second year; *W.s.*3, spring wood of third year; *Cbm.*, cambium; *m.r.*, medullary ray; *c.c.*, cork cambium; *bk.*, bark; *Ph.*, phloem (× 16.).

(*T. D. Tuton Hall.*)

In some plants, there is scarcely any stem at all. Therefore, the leaves of such plants must be borne very near the soil. In such cases, the leaves are usually large and overlap each other, the whole leaf pattern lying firmly against the soil surface. Such leaves clearly must be large in order to get sufficient light for the manufacture of food. Lying flat against the soil and radiating outwards from stem axis, they form a kind of rosette; hence such plants are said to be of the **rosette** habit (Fig. 139). Two well-known examples of rosette plants are plantain (*Plantago media*) and dandelion (*Taraxacum officinale*) (Fig. 140). They naturally take up a considerable amount of soil area, for no other plant could hope to develop under their spreading, recumbent leaves, and that is why both these plants are considered such objectionable weeds on lawns, tennis courts and golf greens.

Then, there are other plants which possess the opposite type of stem, that is, exceptionally long, sometimes many yards in length. As such stems are not thickened in the same proportion, one of two things must happen. Either the stem must lie recum-

bent on the surface of the soil, a straggling, helpless structure, or it must be supported by something stronger. Both types exist. The former is called a **creeping stem** and the latter exists in several forms.

Creeping stems are not very common (Chap. IV). They are, however, present in a few well-known British plants, such as the moneywort (Fig. 54) and *Abronia*, a cultivated plant. At the

FIG. 139. THE ROSETTE HABIT OF PLOUGHMAN'S SPIKENARD.
The surrounding plants are ground ivy.
(*Photo. Henry Irving.*)

nodes of such plants, adventitious roots are given off, a shoot is formed, and thus a young plant is often produced.

In the kind of elongated stem which depends upon some form of support, there are several types. For example, there is the ivy with its long trailing stem, sometimes stretching for many yards up the trunk of a supporting tree. In this case, the stem of the ivy clings to its supports by means of adventitious roots. Other plants cling to their supports by means of tendrils, as has already been seen (Chap. IV).

Then there are the well-known types of plants which coil

round their supports. They are known as **climbing plants.** Such plants are very prevalent in the luxuriant tropical forests; but there are also well-known British types, some of which are familiar garden plants. The climbing plant coils round its cylindrical support in a spiral fashion. The support is, in Nature, of course, the stem of a stronger erect plant; but often in culti-

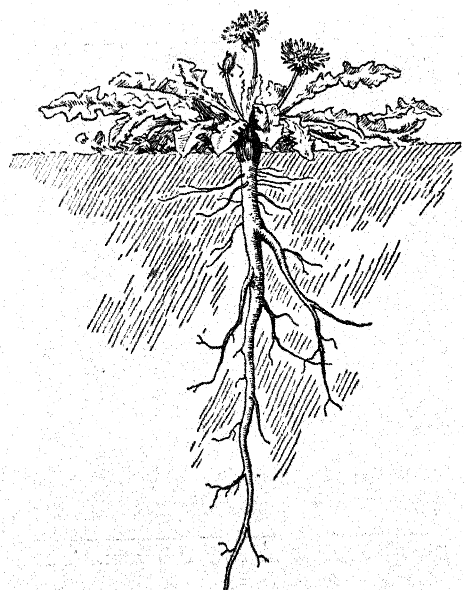


FIG. 140. THE ROSETTE HABIT AND ROOT SYSTEM OF THE DANDELION.
(*After Bailey.*)

vation it is the branch of a dead tree or shrub, or even string, put there for the purpose.

There are two ways in which a spiral can be formed around a cylinder—clockwise and anti-clockwise. Both forms exist in the spiral stems of climbing plants. In the French bean, convolvulus and gourd it is anti-clockwise (Fig. 141), whereas in the honeysuckle, hop and black bryony it is clockwise (Fig. 142) (see Chap. XXII). Usually, in temperate regions, the climbing

plants are all herbaceous, as in the runner bean; but in the tropics, the luxuriant growth of climbing plants is often formed of woody—that is, secondarily thickened—stems. In this case, they are often called **lianes.**

The stems of many plants are of economic importance to man. Some of them are so familiar that they need not be considered

FIG. 141. CONVOLVULUS CLIMBING AN OAT STEM. (*Photo. Henry Irving.*)

here. Others, on the other hand, are much modified, and it is due to their modified structure that they are useful. For example, the potato bears swollen underground stems which are called tubers (Chap. IV). Here, much food is stored by the plant, chiefly in the form of starch. Thus the potato tuber is of great value to man, as has already been seen, as a farinaceous food and for several other reasons. Its value depends chiefly on the starch present.

Straw

The greatest uses of plant stems, however, are found in the types which are dead, for example, **straw.** This commodity is formed from the dead and dried stems of cereals, especially wheat, barley and oats. Straw has many economic uses which have long been recognised. It was probably used in the first place as bedding for mankind and as fodder and litter for cattle; and later it found a use for thatching buildings.

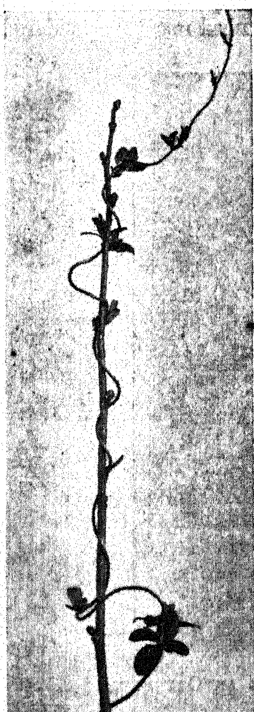


FIG. 142. YOUNG HONEYSUCKLE CLIMBING A HAZEL SHOOT.
(*Photo. Henry Irving.*)

To-day straw is used for many articles of commerce. For example, it is used in mat-making, the stuffing of cheaper forms of bedding, the weaving of hats and baskets, twisting into bands for binding sheaves of corn, in various forms of ornamentation, and in making pulp for the manufacture of paper and cardboard. For paper manufacture, the straw is chemically treated until it forms a pulp which is capable of passing through the rollers. In hat- and mat-making, a special kind of straw is used. This kind is produced especially in Bedfordshire, Buckinghamshire and Hertfordshire, in Great Britain, and also in Italy and China.

Forestry

The most useful of all stems to mankind are those which supply timber. The trunks of trees have so many commercial uses, that the cutting down of trees is not now a mere haphazard affair, but a systematic process. For example, in the early days of the settlement of America, the settlers encountered huge forests, so thick that settlement was quite impossible until some of

the trees had been removed. This was done and the wood thus obtained was used for building log cabins, constructing stockades against the hostile Indians, making furniture, etc. The logs thus felled were referred to as **lumber**, since they were not considered to be of very much value. Later on, however, the settlers began to realise the value of this lumber, and they even began to

FIG. 143. A RAFT OF CANADIAN TIMBER APPROACHING THE MILL.
(Reproduced by kind permission of the Controller, H.M. Stationery Office.)

export it. Thus the great lumbering industry of the United States and Canada developed, and to-day it is one of the most important industries of that continent (Fig. 143).

Wood is roughly classified into **hardwoods** and **softwoods**. Misleading though it is, these names do not denote the degree of hardness. Hardwoods are obtained from angiospermous trees such as the oak; whereas softwoods are obtained from gymnosperms such as the pine. About 83 per cent. of the woods produced by the United States to-day are softwoods, the chief plants supplying these being the **southern pine** and the **Douglas fir** (*Pseudotsuga Douglasii*). An even higher percentage of softwoods come from Canada.

Logging is one of the most interesting processes in lumbering; that is, getting the tree trunks from the region where they are felled to the sawmills. In the early days, felling of the trees took place in the late autumn and winter, and then the logs were conveyed to the river by means of sledges. During the spring, the logs were got into the river, usually by merely sliding them down over the banks and then allowing them to float in huge masses down to the sawmill. Very often they were chained together to form huge rafts so extensive that the lumber-men built cabins actually on the rafts. At the present time, there is no need to wait for winter conditions in order to make use of sledges. In the woods themselves, railways have been constructed from the scene of the tree-felling to the river. This saves a great deal of time.

It is quite clear that throughout the ages, the relations between man and forests have been many and varied. Sometimes the forests were useful for the trees they produced, and at others they were useful as forests; that is, they were kept for some specific purpose. For example, many forests, for centuries, were kept for the purpose of hunting. No trees were allowed to be felled. That happened on the Continent and on these islands for several centuries. Some small copses are kept for sheltering game, and certain woods for harbouring deer, even to-day in Great Britain and other countries.

In the early days of civilisation, forests were a great drawback. For that reason, nearly all remains of primitive man which have been discovered came from moorlands and other parts not dominated by forests. So also did the early Egyptians, Babylonians, etc. The tools of early man were too crude to deal with the domineering forest lands. Later on, however, as tools were developed and man became more civilised, the forests began to suffer, for more space was needed. Forests were also a great barrier to travel. To-day, of course, except in some tropical regions, especially those in central Africa and the valley of the Amazon, man has conquered the forests, from this point of view.

But the wholesale breaking up of forests has gone far enough. We realise to-day that forests have their uses, not only as sources of wood for commercial purposes, but also from other points of view. Therefore, although in some cases cutting away the forests,

called **deforestation,** can still go on, in other cases the planting of new forests, called **afforestation,** is taking place.

Thus the subject of forestry has assumed such gigantic proportions that it has now become an important science, and the problems of deforestation and afforestation have come under systematic control. Even in Great Britain we have recently learned the lesson that we must not go on cutting down trees in a haphazard fashion. During the War, timber was required in great quantities. Naturally, in that state of emergency, deforestation went on to a great extent. Now, there is a shortage in many parts of the country, and a reaction has set in. Gradually the forests are being replaced by the planting of young trees, called saplings, but even this is done systematically by the scientific forester, who knows where trees will grow best, where they will do most good, and which type of tree will suit any given locality.

In 1920, afforestation began in real earnest in Great Britain, and up to 1927 (only seven years) nearly 95,000 acres had been afforested and nearly 400,000 more acquired by the State for afforestation. In the United States, from 1920 until 1932, 33,000,000 more acres had been afforested, so that at the present time there are nearly 496,000,000 acres of forest land. To-day, in India, the various Government forest estates, where certain trees are cultivated for numerous commercial purposes, exceed more than 45,000,000 acres; and then there are even more than this number of acres owned by the villages and private persons, bringing the Indian forest area up to nearly 100,000,000 acres.

In the large forest areas of the world, the greatest enemy of afforestation is forest fires. So serious are they that in some places men are employed specially to fight them and to warn others by means of telephone and radio. Insect and fungal pests also kill many forest trees annually.

Physiographical Effect of Forests

Forests have important effects on soils, climate, etc. There is little evidence that they actually influence rainfall, but they certainly do conserve much of the water which reaches the

soil. In level country, also, they clearly act as a great drainage system. Owing to this property, great areas of marshland on the Continent have recently been drained off by a process of afforestation. In hilly country, forests prevent a too rapid run off of surface water, and thus help in maintaining a steady stream-flow from the hillside, instead of torrential streams during the wet season and a dried-up condition during the dry season.

Soils tend to break up owing to various actions of the weather. This will be considered later on (see Chap. XXIII). The breaking up of the soil is called **soil erosion**, and although in some cases the process is a useful one, in others it is undesirable. Forests tend to prevent soil erosion. The deeply penetrating roots of the trees hold the soil more firmly in place. This fact is applied in coal-mining areas. There, the very soft rocks, which are waste products from the mines, are taken by special rail waggons and deposited on some waste land near by. These mounds of waste soon assume such great dimensions that they become veritable hills. No more waste rock is then deposited on them. But, unfortunately, the rock is so soft that erosion soon takes place and there is a danger of the mound slipping, thus causing what might be a dangerous landslide. This is prevented by planting over the whole of the surface certain trees. Any kind of tree will not do, since the soil which results from the erosion of this waste rock is very infertile and naturally very dry. The trees used are certain species of pine, chiefly the Scots pine (*Pinus sylvestris*) and the larch (*Larix europœa*).

The forests, used by man to-day for the woods they produce, may be roughly divided into three groups. (1) **Conifers** : these are all softwoods and are confined to the cooler regions of the globe. The main types of softwood trees are pines, spruces, firs, larches, cypresses and sequoias. (2) **Temperate hardwoods** : the most important trees in these forests are oak, maple, birch, poplar, elm and beech. (3) **Tropical hardwoods** : these contain mahogany, ebony, teak, logwood and rosewood.

Much research work in connexion with forestry is being done at the present time all over the world. The most important centres for such research in Great Britain are at the Forest Products Research Laboratory, Princes Risborough, the Im-

perial Forestry Institute at the University of Oxford, and the School of Forestry at the Universities of Cambridge, Aberdeen and Edinburgh.

Grafting

As has already been seen in Chap. IV, many stems, owing to their ability easily to produce adventitious roots, form methods of vegetative reproduction, for example, stolons, runners, etc.

There are other ways of reproducing plants vegetatively, through the media of their stems; but these ways are artificial in that they seldom exist in Nature but are only performed by man. They are, however, of great importance to the modern gardener and horticulturalist. One of these artificial methods is that familiarly known as **grafting.**

Grafting, as an artificial process, is of the greatest importance, not only to botanists but also to zoologists and medical men; for the process is practised in animals, including man, as well as in plants.

The process involves fixing two pieces of cut tissue together firmly, with the result that they gradually grow together to form one piece. It is useless to choose *any* two pieces of tissue. They must be similar, and they must both be composed of living cells. For example, it would be useless to try and graft a leaf on to a root; neither would two pieces of wood, which is composed of dead elements, graft together.

Fundamentally, the grafting involves bringing together the cut surfaces of parts of two different plants, so that their *growing* tissues come into contact with each other. Since it is usually stems which are grafted, the growing tissue is the cambium, and it is therefore necessary that the cambium of one part comes into direct contact with the cambium of the other. Another important thing is that only plants which are closely related to each other can be grafted together. For example, a piece of an apple tree cannot be grafted on to a piece of a plum tree. Two varieties of apple can be grafted, or an apple on a pear, or a garden rose on a dog rose, and so forth. That part of the plant which is still connected to the root in the soil is called the **stock;** the other plant used in the process is called the **scion** or **graft.**

There are two forms of grafting common in horticultural practice. One is called **whip or tongue grafting** (Fig. 144). It is best used when the stem of the stock and the stem of the scion are about equal in diameter. Both are cut across diagonally. A vertical notch is made in the stock, and the scion is cut more or less chisel-shaped. Then the tongue of the scion is dovetailed firmly into the notch of the stock, and the joining portions firmly held together with raffia. The wound is protected by surrounding the whole with a thick layer of wax or clay.

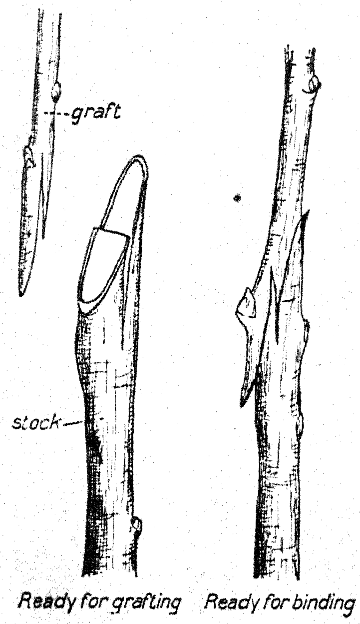


FIG. 144. WHIP GRAFTING.

The other method of grafting is much simpler and is called **splice grafting**. Both stock and scion are cut across obliquely at about the same angle, and the two then fixed firmly together in a manner similar to the above.

There are several reasons for grafting. In this way, a cheap, easily obtained, and vigorously growing stock can be used on which to graft a valuable scion. It is certain that by this method we shall perpetuate any definite type of fruit that we need. A very important reason for grafting is that fruit and flowers can be produced much more quickly by this method than from seedlings or seeds.

During the winter months, of course, many types of trees are 'sleeping'; that is, their tissues are carrying on their life processes at a very slow rate. It is clear that in the case of grafting, vigorously growing tissues are required in order that the union of the tissues of stock and scion (which involves the production of new cells) may take place quickly. Therefore, it is

useless to graft trees during the winter. Spring is the best time for this, for then both stock and scion are full of health and vigour.

The placing of clay or wax around the position of the graft is not so much to reinforce the support of the raffia as to prevent evaporation from the wound and the entry of disease-forming bacteria. In practice, varieties of rose are usually grafted on to stocks of the wild or dog rose. The stock forms a tall, strong central stem for the resulting rose tree. In this way does the grafted tree differ from the normal ungrafted rose **bush.** Such grafted trees are called **standard trees.** Varieties of rhododendron are grafted on to stocks of the wild variety, apple trees on the wild or crab apple, pear trees on the quince, and cherries and plums on their wild varieties.

Budding

In the practice of horticulture, closely allied to grafting is the process known as **budding.** The essential factors in grafting are just as potent here. The process involves taking a single living bud of the tree which is to be propagated, and grafting it on to the stock of another. The bud is removed, together with a certain amount of the stem tissue to which it is attached (Fig. 145). This portion is roughly diamond-shaped and must have, together with the bark, some wood and some cambium and phloem beneath. A vertical cut is then made in the stock about an inch long and going deep into the wood. Across the top of this cut a horizontal cut is made of about half an inch; thus giving

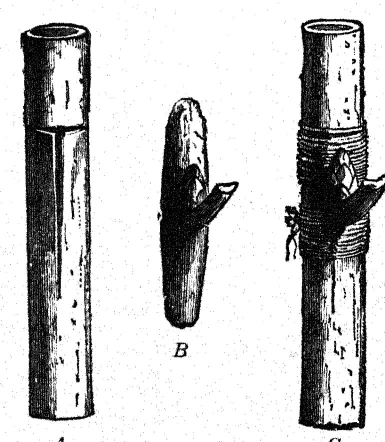


FIG. 145. METHOD OF BUDDING. *A*, incision made in outer tissues of stock; *B*, bud; *C*, bud inserted. (*After Figuier.*)

a T-shaped incision. Then the corners of this incision are lifted with a knife and the bud inserted with the diamond-shaped stem portion beneath the flaps and the wood of this portion pressing firmly against the wood of the stock. The whole thing is then bound with raffia.

After about three weeks, it will be found that the bud has grown on to the stock, and then the raffia should be cut and allowed to fall off in its own time. If it is left tied too long it may, through its tightness, do permanent injury to the young bud. Eventually the bud will grow out and produce a branch of its own type. Budding is usually performed later than grafting, that is, in early summer when the bark is easily lifted. In budding, care should be taken to remove all true buds of the stock else they will eventually develop and take much of the food materials rising in the stock away from the grafted bud which is required to develop. Budding is carried on chiefly in the cultivation of roses, plums and peaches.

PRACTICAL WORK

1. Prepare a transverse section of a dicotyledonous stem for detailed examination under the microscope. Almost any stem of an annual will serve the purpose ; the sunflower is a good example.

Mount the section and irrigate with an aniline salt, in order to stain the woody tissues. Examine and draw the whole section under the low power of the microscope, with the view of illustrating the various tissues. Make no attempt, at this stage, to show cellular structure. Note the epidermis, cortex and central cylinder. Look for any layers of the cortex which may be thickened to give additional strength. Note the vascular bundles composed of xylem, phloem and cambium. Note the position of the protoxylem and, from this, deduce the direction of development of the metaxylem. Compare this with that in the root. Note the pith, and see if the stem is solid or hollow.

Then examine the stem under the high power and note the cellular structure in detail. Make two drawings ; one of the epidermal and some of the cortical tissues, and the other of a complete vascular bundle.

2. In a similar way, examine the structure of a monocotyledonous stem. That of the maize is a good example. Under the low power note the small size, large number, and irregular arrangement of the vascular bundles.

Under the high power, note especially the complete absence of cambium.

3. Make a detailed examination, by means of transverse sections, of a secondarily thickened stem. A twig of the lime or horse-chestnut three or four years old is good material upon which to work.

The various stages of secondary thickening can be examined very well by taking several transverse sections through the stem of various ages. The following will act as a guide: (1) near the apex of the shoot; (2) the middle of the first year's growth; (3) near the bottom of the first year's growth; (4) about the middle of a later year's growth.

Make low power sketches of the various stages, then examine a completely secondarily thickened portion in detail, and prepare drawings of the various tissues. Note the secondary wood and examine the vessels of the spring and autumn wood. Look for medullary rays. On the other side of the cambium, note the secondary phloem, containing certain thickened cells known as phloem fibres. Note how the medullary rays widen out in the phloem. Near the periphery, look for cork cambium, and note the layers of cork cells produced on the outside of this. Further out again, the tissues are shrivelled up, since they are cut off from a supply of water, and have produced the bark.

4. In a similar way, examine the structure of a secondarily thickened root.

Field Work

While on a botanical excursion, or taking a walk in the country, look for and examine examples of creeping and climbing stems. In the case of the latter, note the direction in which the stems are twining around their supports. Note the type of supports which such plants choose. Collect a few examples, taking just a small portion, if possible, with a part of the support. Draw these examples and describe them when opportunity permits.

Some twining plants may be seen growing in the garden.

Those who have the opportunity should practise budding and grafting, either in the school garden or at home. Budding is usually performed in July and grafting in March. Suitable material should be chosen, so that good results may reasonably be expected.

If there is little opportunity to practice this in the garden, so that results could be looked for in later years, twigs and buds could be taken into the classroom and the elements of the process practised there. The great drawback to this alternative is that results cannot be obtained.

Failing either of these, one should try to obtain permission to visit a nursery garden or a private garden to see budding and grafting taking place.

CHAPTER X

THE LEAF

FROM the point of view of the well-being of the normal green plant, the leaf is one of its most important organs. It is the organ which is responsible for the manufacture of the various foods which the plant requires.

External Appearance of Leaf

The general external features of the leaf have already been considered to some extent (Chap. III). It is composed chiefly of a flattened expansion called the lamina, and very often a leaf-stalk or petiole. Apart from variety in shape, the majority of green leaves are similar in their essential features. For example, they all contain chlorophyll, the green colouring matter responsible for the manufacture of the food-stuffs—carbohydrates, etc.

Another important feature of the leaf is the vein. A leaf vein is nothing but a vascular bundle, similar to the type that is found in the stem. In fact, it is one of the bundles passing from the stem up through the leaf stalk and into the leaf. It is thus composed chiefly of xylem and phloem; from which it follows that the function of the vein is mainly twofold. Through the agency of its xylem it conveys the water which passes up the stem from the soil into the leaf, where it is required for the manufacture of food, as a raw material, and also for other purposes which will be dealt with later. Secondly, the sieve tubes in the phloem of the veins are used for conveying the food manufactured in the leaf, in the form of a solution, down into the stem and hence, through the vascular bundles, to all parts of the plant where it is required.

Autumn Leaf-fall

As is well known, the majority of plants which are long-living perennials are shrubs, bushes or trees. In the tropics, these are mostly evergreen; but in temperate regions, such as Great Britain, the majority are deciduous. The reason for that is not far to seek. Temperate regions experience two definite seasons during the year, namely, winter and summer. Winter is not conducive to the good growth of a plant, since a low temperature and lack of sunshine have a bad effect on nearly all life processes. On the other hand, summer weather is ideal.

Therefore, the plant enjoys vigorous health and growth during the summer months, whereas during the winter it undergoes a period of comparative rest. Even in winter, however, all life processes do not cease, else, of course, the plant would die. It just carries on the minimum work necessary in order to live, just as we do when we are sleeping.

Therefore during the winter the living plant requires the minimum amount of food. In fact, it usually manages to store enough food to carry it over the winter; so there is no necessity to continue manufacturing food. For that reason, the food factories are temporarily abolished, and thus the familiar **leaf-fall** of autumn takes place. At the same time, the rise of water from the soil, through the roots and up the stem, is temporarily abandoned. For one thing, this water is no longer wanted, since the leaves have fallen, and also it could not rise even if it were wanted. That is because, as will be seen in Chap. XII, the leaves are an important agent in the rise of this vitalising sap in plants. Therefore, when the leaves begin to burst forth again from the buds, in spring, the water is drawn up again. That is what is meant by the rising of the sap in the spring.

As is well known, leaf-fall is usually preceded by a change in colour of the leaf itself. During the autumn, the leaf gradually loses its characteristic green colour and changes into many beautiful shades of yellow, brown and red. This gives the gorgeous tints which add such a delightful touch to the appearance of woodlands and forests at that time of the year. This change is connected with the chlorophyll. In the autumn, the

chlorophyll begins to disintegrate chemically. What exactly takes place is not clearly understood yet; but we do know that the chemical substances present in the chlorophyll undergo a change and become converted into other chemical substances of the various colours familiar to us in the autumn (see Chap. XI).

With the disappearance of chlorophyll, the manufacture of new food materials naturally ceases. Thus there comes a time when the leaf no longer contains food substances, and then, as a food factory, it is useless. Then leaf-fall sets in.

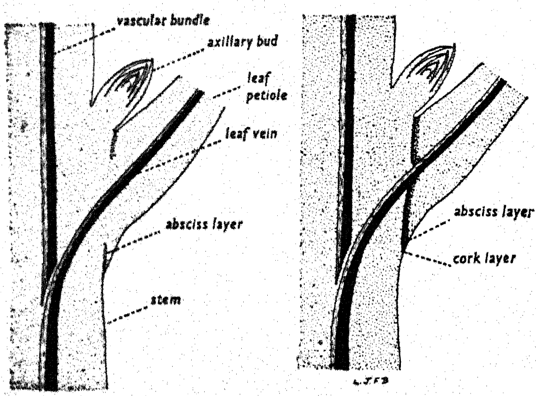


Fig. 146. Parts of Longitudinal Sections through a Stem, passing through a Leaf Base, showing Stages in Leaf-fall.

On the left, the absciss layer beginning to form; on the right, absciss and cork layers almost completely formed.

Nearly always the leaf blade and the leaf stalk are removed from the tree, leaving the characteristic leaf scar (Chap. III). But leaf-fall is a systematic process. It does not involve just the mere rotting away of the tissues at the base of the petiole.

Across the whole of the leaf base a certain area of parenchymatous cells begin to change their shape and become spherical (Fig. 146). They are said to round themselves off. The layer which does this is several cells in thickness. The rounding-off process begins in the outer tissues of the leaf base and gradually

works its way across it. Now, since all these cells were originally joined firmly to each other, as they round themselves off, they naturally become detached from each other. Naturally by the time all the cells in a complete cross-section of the leaf base have done this, that area is no longer firmly knit together and there is, therefore, nothing on to which the leaf may hold. Thus, by virtue of its own weight, it falls off.

However, this is not the only process which takes place. If it were, it would mean that there would be a bad open wound of thin parenchymatous living cells left at the end of the fallen leaf base. This is prevented by a process which takes place simultaneously with the rounding off of the parenchymatous layer, which is called the **absciss layer.**

While the cells gradually become exposed by this rounding-off process, the layers of cells immediately beneath deposit cork on their walls. This goes on at such a rate that, by the time these cells are completely exposed, they are no longer living, but are just thick cork cells. The result is that, when leaf-fall is complete, a layer of cork is left covering the wound on the stem. The leaf scar seen on a winter twig is really an area of cork, and the marks left by the vascular bundles, which originally passed up into the living leaf, may clearly be seen.

Leaf-fall is a very efficient process, for the leaves make sure of bandaging their wounds, by manufacturing the covering bandage of cork before the wound is made. Thus, the wound caused by the breaking off of a leaf during leaf-fall is never exposed to infestation by rain and disease-bearing bacteria, etc.

Special Uses of Leaves to Man

Many leaves are used as articles of diet. For example, green leaves are used for helping to keep the blood in a good condition. The leaves of plants form a staple diet of many animals, both temperate and tropical.

We ourselves eat leaves in many various forms. Many are eaten in the raw state, for example, cress, mustard and lettuce, in salads. Cooked leaves are very familiar, such as the various forms of cabbage, turnip 'tops' and spinach. Others are used

for seasoning purposes, such as **thyme, parsley, sage** and **mint.** Thyme is one of the most useful of herbs. The plant, *Thymus vulgaris*, is native to Europe. The leaves are used in seasoning. Also, from the leaves, an oil is extracted from which *thymol* is prepared. Thymol is an important medicine. Parsley is a seasoning obtained from the leaves of *Petroselinum sativum*, a biennial. This plant is seldom found growing wild. Sage (*Salvia officinalis*) is native to south European countries. To-day it is used in seasonings and perfume, though formerly it was used in the treatment of rheumatism. From the leaves of mint (*Mentha viridis*) the well-known seasoning is prepared; with vinegar, etc., it is also used for making mint sauce.

A well-known leaf, which will be dealt with later on, is used for making the very familiar beverage, tea (Chap. XVII). Tobacco, also, is prepared from the leaf (Chap. XVII). Then there are many types of leaves which for various reasons are used as medicines, etc. (Chap. XVII).

Internal Structure of the Leaf

Besides the framework of the veins, there is a mass of tissue which constitute the leaf proper (Fig. 147). All the cells of this tissue are usually unthickened, and therefore the leaf is of a soft texture: hence, the veins have another function besides conveying water and food-stuffs to and fro; that is, they act as a kind of skeletal support to the tissues of the leaf.

This is well illustrated by the manner in which deciduous leaves often decay after they have fallen. It is frequently possible to find such decayed leaves, especially in woods. All the soft tissues of the leaf have rotted completely away, leaving the dried-up veins forming a beautiful skeletal framework still mapping out the shape of the original leaf. Net venation can be studied from such an example.

The soft tissues are collectively known as **mesophyll**. The mesophyll is covered on the upper and lower surfaces by a layer of cells called the **epidermis**; the layer on the upper surface being called the upper epidermis, and the layer on the lower surface the lower epidermis. The elements which comprise the veins of the leaf contain no chlorophyll; neither do the cells of the epidermis,

except the guard cells. On the other hand, nearly all the cells of the mesophyll contain chlorophyll.

The mesophyll is composed of two tissues of different cells. The upper tissue lies against the upper epidermis. This is composed of elongated, cylindrical cells, arranged perpendicular to the epidermis. Owing to its appearance it is called the **palisade tissue.** It is composed of two to three layers of cells. These palisade cells contain by far the most of the chlorophyll. On examination, it will be seen that the chlorophyll is not present

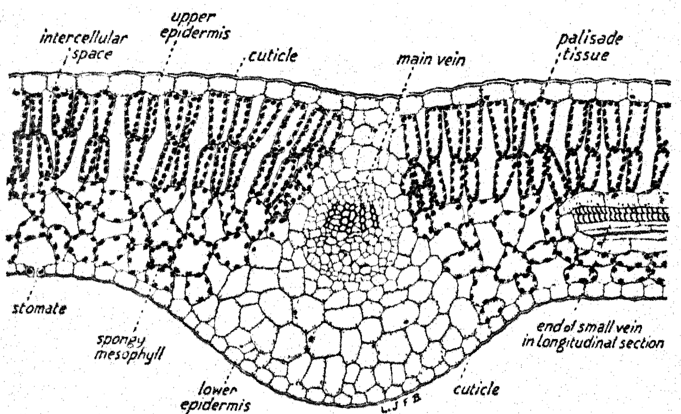


FIG. 147. TRANSVERSE SECTION OF PART OF A LEAF, PASSING THROUGH THE MIDRIB (×100).

just as a simple green colouring matter dissolved in the protoplasm or the cell-sap. It is actually present in small grains, shaped like flattened oval discs. These grains are called **chloroplasts,** and are not immersed in the cell-sap but are embedded in the protoplasm and move about with it. There are more chloroplasts in a palisade cell than in any other cell in the leaf. The palisade cells are not packed closely together. There is a certain amount of space between them, which is necessary. These spaces between the cells are called **intercellular spaces.**

The lower tissue of the mesophyll is called **spongy tissue,** owing to its spongy texture. It is composed of more or less spherical cells which are joined very loosely together, with very large air

spaces between them. Thus, throughout the spongy mesophyll there is a network of air channels. The cells of the spongy mesophyll also contain chloroplasts. Therefore, the whole of the mesophyll, including palisade and spongy tissues, forms the seat of food manufacture; but photosynthesis takes place to a greater extent in the palisade tissue, since it contains many more chloroplasts, cell for cell, than the spongy tissue does.

This, in any case, is to be expected in the normal leaf since sunlight is necessary for photosynthesis to take place, and the palisade tissue in such a leaf is more directly exposed to the sun. On the other hand, as has already been seen, much gaseous interchange goes on between the inside of the leaf and the atmosphere. The spongy mesophyll is better adapted for this function, owing to the many air spaces it contains. The walls of the spongy mesophyll cells are usually wet on the air space side. Thus the various gases required by the plant become dissolved in this surface water and then pass into the cells, *in solution*. Then the solution passes from these cells to the others where it is required. Similarly, dissolved gases pass out from the cells.

The epidermal cells, since they do not contain any chloroplasts, are not photosynthetic. Actually they are used for storing water; also for preventing evaporation of water from the leaves. This latter function is made possible by the deposition of what is called a layer of cuticle on the outer walls of the epidermal cells. This cuticle is chemically similar to fats, and, like those substances, will not allow water to permeate through it. It is usually thicker on the upper surface than on the lower surface of the leaf, since it is from the upper surface that more evaporation is likely to take place.

The cuticle of evergreens is usually thicker than in the more normal leaf. That is because they have to withstand more evaporation. This thicker cuticle gives such leaves a shiny, greasy appearance, for example, the holly. The reason for this, too, is to prevent snow or excess rain, to which an evergreen is subject, from penetrating the epidermis and causing the leaf to rot.

Sometimes the outer cell-walls of some of the epidermal cells

grow out to a considerable length, thus giving rise to hairs. These may be simple, branched or star-shaped (Fig. 148).

An interesting type of hair produced by the epidermis of the leaf is that, unfortunately all too familiar, of the stinging nettle (*Urtica dioica*) (Fig. 148). The tip of the hair contains silica and

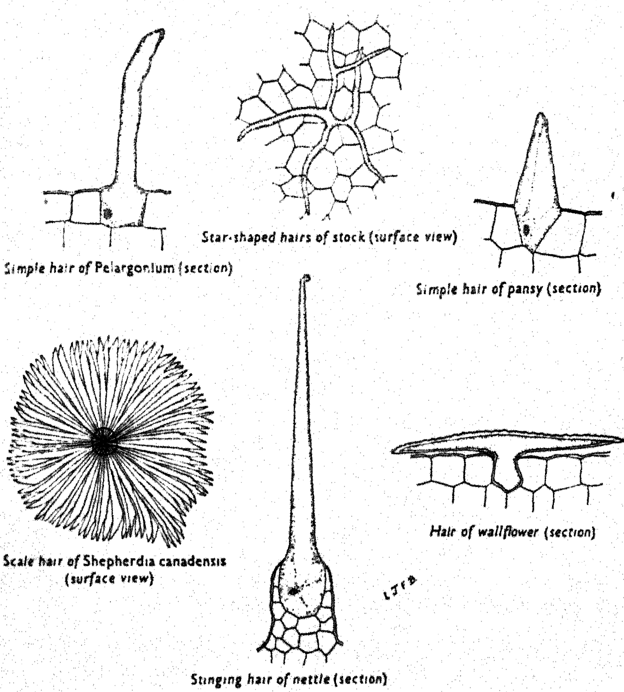


FIG. 148. TYPES OF EPIDERMAL HAIRS FOUND ON LEAVES.

is therefore brittle. When this is touched, for example, by the hand, it breaks off, the sharp point of the hair enters the skin and, by the pressure exerted on the bulbous portion of the hair, the contents of the hair are injected into the puncture. The poisonous content of the hair was, for a long time, considered to be formic acid. This has now been disproved. It is a protein, the composition of which is, at present, not known.

Stomates

It has already been seen how gases leave or enter the cells of a leaf; but, so far, only from the inside of the leaf, that is, the air spaces of the spongy mesophyll. The next question is: how do the gases pass from these air chambers out into the atmosphere and vice versa? This takes place via certain pores which are present in the epidermis. These pores are called **stomates**, or stomata (Fig. 149 and 150). Each stomate, or stoma, is surrounded by two, normally kidney-shaped, epidermal cells, which

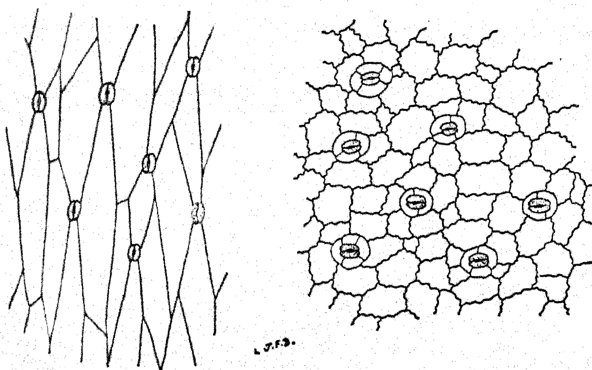


FIG. 149. SURFACE VIEWS OF LEAVES, SHOWING THE EPIDERMAL CELLS AND STOMATES SURROUNDED BY THEIR GUARD CELLS.

On the left, iris; on the right, potato (× 70).

are called **guard cells**, since they are able to move, as will be seen in Chap. XII, and thus regulate the amount of gases passing through the stomate. The guard cells, too, are the special epidermal cells, which, unlike the rest, contain chloroplasts. The stomates are directly connected with the air chambers of the leaf, and thus a free passage of gases is possible, from the atmosphere into the inside of the leaf and vice versa.

Most commonly, of course, the stomates are connected directly with the air spaces of the spongy mesophyll. Therefore, as would be expected, there are many more stomates per unit area on the lower surface than on the upper surface of the leaf. For example,

in the lilac, there are 160,000 stomates per square inch on the lower surface of the leaf, and only 3 to 10 on the upper surface. In the holly, there are 63,000 per square inch on the lower surface, and none on the upper.

Taking into consideration the reasons for the various tissues of the leaf and also the different habits of different leaves, there are, as would be expected, many interesting exceptions to the general structure of leaves. They all cannot be considered, but

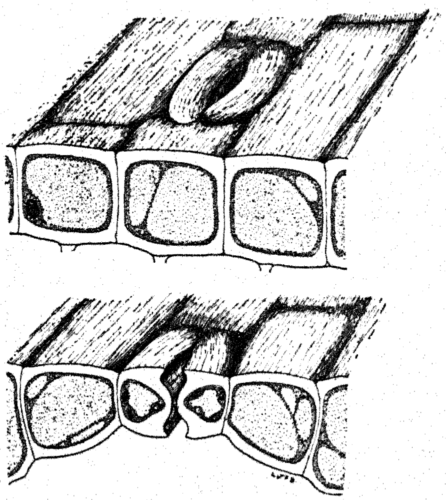


FIG. 150. ABOVE, A DIAGRAMMATIC VIEW OF PART OF THE EPIDERMIS, SHOWING A STOMATE; BELOW, THE SAME CUT IN SECTION.
Note the shape of the guard cells which contain chloroplasts.

a survey of one or two familiar examples will give some idea of how Nature knows no hard and fast rules.

For example, in the case of an upright-growing leaf such as the iris, it would be pointless to have the palisade tissue on one side and the spongy mesophyll on the other, for both sides are equally exposed. In this case, therefore, there are two layers of palisade tissue, with the spongy tissue between, that is, in the centre of the leaf. The stomates, too, are present in equal proportions on both surfaces, namely, about 11,600 per square inch.

In the case of a water-plant with floating leaves, for example, the water-lily, stomates in the normal position, that is, on the lower surface, would be worse than useless, for they not only would allow of no access to air, but they would also cause the internal parts of the leaf to be flooded with water. In this case, therefore, all the stomates are on the upper surface.

PRACTICAL WORK

1. Choose a simple form of leaf, such as that of the elm, beech, apple, or *Hydrangea*, and examine its external appearance in detail. Make a clear drawing of the leaf, showing the swollen leaf-base, the petiole and the lamina. Examine the type of venation, and note how the veins gradually diminish in size, until the ultimate branches are scarcely visible.

2. Make a detailed examination of the internal structure of a typical leaf. This is done by preparing a microscope section of the leaf, cut transversely. Prepared sections may be used; but if time permits, it is better to make such sections. Naturally only a portion of a leaf can be cut successfully. Choose a small portion of the leaf (such as lilac or *Hydrangea*), which contains some of the mid-rib, and fix it between two pieces of elder pith or carrot root, in such a position that the mid-rib may be cut transversely. Mount the section and stain with aniline sulphate.

Examine, first of all, the whole structure under the low power and make an orientation sketch of the tissues, noting the upper epidermis covered with a layer of cuticle, palisade tissue, spongy tissue, and lower epidermis covered with a slightly thinner layer of cuticle. Note also the vascular bundle forming the mid-rib, composed chiefly of xylem and phloem.

Then make two detailed sketches, (*a*) of the mid-rib embedded in a sheath of parenchymatous cells and (*b*) the thin portion of the leaf. Here, note the absence of chloroplasts in the upper and lower epidermis, a large number in the palisade mesophyll cells and a relatively smaller number in the spongy mesophyll cells. Note the shape of the chloroplasts.

Examine the shape of the cells of the palisade tissue and note the number of layers here. The cells are separated by small air spaces. Note the more or less spherical shape of the cells of the spongy mesophyll, and the presence of large air spaces in this tissue.

3. Prepare a section of a thick evergreen leaf, such as that of the holly, and note and explain the relative thickness of the cuticle.

4. Detailed examination of the stomates is best made on material like that of the iris leaf.

In surface view. Take a small portion of such a leaf, and carefully tear away the epidermis. This comes away fairly easy as a

thin, tissue-like layer. Mount this flat and examine it under the high power of the microscope. Look for a stomate and draw it, with several of the surrounding cells. The stomate is just a small pore, surrounded by two kidney-shaped guard cells. Note that whereas the guard cells contain chloroplasts, the normal epidermal cells, in which they are embedded, do not.

In section. Cut a transverse section of the leaf and look for a stomate cut in section. Make a drawing of this structure under the high power. Notice the shape of the guard cells and of the stomate itself. Note also the large air space in the mesophyll, immediately adjoining the stomatal pore.

5. Make an orientation sketch of the tissues of the iris leaf as seen in the section prepared for Exercise 4, and also of a leaf gathered from the outer twig of a beech tree and from a twig in the dense shade near the trunk of the same tree. Explain the different types of sections which are obtained.

CHAPTER XI

MANUFACTURE OF PLANT FOOD

ONE of the most important processes with which all living things are concerned is the manufacture of the very complicated food-stuffs—carbohydrates, proteins, fats, etc.—from the raw materials. In Nature, this is only possible in the presence of chlorophyll, and for that reason, green plants are of the utmost importance to all forms of life. From the immediate point of view of the green plant, its leaf therefore is a very necessary organ, for, in its capacity as chlorophyll-containing organ, it acts as the food factory. From a broader point of view, the green leaf is one of the fundamentals of all life, for all life on this earth, either directly or indirectly, depends upon it for food. The saying in Isaiah, xl. 6, that "All flesh is grass," has scientific truth in it, generally speaking, so long as 'grass' is taken as meaning green plants; for though many animals, including ourselves, do not eat 'grass,' they feed on animals which do, especially cattle and sheep.

This process of building up food, since it essentially depends upon light, is called **photosynthesis.**

Chlorophyll

A great deal of our knowledge of chlorophyll has been obtained by extracting the pigment from the leaves. One simple method, useful in just showing the appearance of the extracted product, is to take a thin green leaf such as that of *Tropæolum*, *Fuchsia* or *Hydrangea* and boil it for a few moments in water. This kills the cells of the leaf, and thus allows the passage of substances out of them to take place more easily, since dead cells lose their semi-permeable properties. Then, all that is needed is a chlorophyll solvent, that is, a substance which will dissolve chlorophyll.

A good solvent is ethyl alcohol. If the dead leaf is placed in the cold alcohol, the pigment will gradually dissolve into it; but the process can be quickened by using boiling ethyl alcohol.

Chlorophyll is remarkable in that it is bright green in transmitted light, but red in reflected light; that is, if the solution is held up to the light, with the light shining through it, it is green. If, on the other hand, it is held up against a dark background, with the light shining on it, it appears red. Chlorophyll is therefore said to be green, with a red **fluorescence**. This property may have something to do with its food-manufacturing properties; but what it is we still do not know.

Extraction of chlorophyll with ethyl alcohol is not a desirable method, if the solution is required for the study of the chemical properties of the chlorophyll, for, chlorophyll and ethyl alcohol react chemically with each other, so that what is present in the solution is not pure chlorophyll, but a chemical compound related to it.

The best solution of chlorophyll is obtained by dissolving the chlorophyll in acetone. The trouble with this method is that acetone will not dissolve out chlorophyll from wet leaves; and, of course, all normal leaves contain a large percentage of water. Therefore, the leaves must be dried first.

The best type of leaf to use is that of the common stinging nettle (*Urtica dioica*). The leaves are gathered and spread out on a floor or table, and allowed to wilt and dry until they are brittle. This takes several days. Then they are broken up and the pieces placed in an oven for still further drying. Then the brittle pieces are rubbed through a hair sieve, thus giving a very fine leaf powder. From this, the chlorophyll is easily extracted by means of acetone. This is the method used by scientific workers who wish to make a detailed and careful study of the chlorophyll.

The chemistry of chlorophyll has intrigued many scientific workers for years in the past. Yet our knowledge of its detailed nature still leaves much to be desired. The name chlorophyll was given to the green pigment at the beginning of the nineteenth century; but it is certain that its importance was realised long

before this, since we have it on record that Nehemiah Grew extracted it from green leaves in 1682 by means of oil. But, up to the beginning of the present century, so many workers had attacked this problem of the nature of chlorophyll, and they had all given such conflicting results, that it is safe to say our knowledge until the twentieth century was very imperfect.

Then at the beginning of this century a very well-known chemist, **Professor R. Willstätter,** began working on this problem and other problems in connexion with the chemistry of plants and animals. He has shown that chlorophyll is not a single substance, but a mixture of at least four—two green and two yellow. The two green pigments are called **chlorophyll *a*** and **chlorophyll *b*.** Chemically they are very complicated. Each of these chlorophylls contain the elements carbon, hydrogen, nitrogen, oxygen and magnesium, and are represented by the empirical formulæ $C_{55}H_{72}O_5N_4Mg$ (chlorophyll *a*) and $C_{55}H_{70}O_6N_4Mg$ (chlorophyll *b*). The other two pigments present in the complete chlorophyll colouring matter is a reddish-yellow substance called **carotene,** and a pale yellow substance called **xanthophyll.** Carotene contains carbon and hydrogen ($C_{40}H_{56}$) ; whereas xanthophyll contains carbon, hydrogen and oxygen ($C_{40}H_{56}O_2$).

So far as we know, the two chlorophylls, *a* and *b*, never exist outside the green colouring matter of plants ; on the other hand, carotene and xanthophyll exist separately in many plants. Carotene, for example, derives its name from the carrot, since it is present in the tap root of that plant, giving it its reddish-yellow colour. Xanthophyll is present in the petals of many flowers, though the substance responsible for the coloration of the majority of yellow flowers is something quite different, as will be seen later.

The percentage of the constituents of chlorophyll in plants varies with the plants (Fig. 151). On the average, however, fresh green leaves contain 0·2 per cent. chlorophyll *a*, 0·075 per cent. chlorophyll *b*, 0·17 per cent. carotene, and 0·03 per cent. xanthophyll.

The foregoing account gives some idea of present-day knowledge of the green colouring matter of plants, the complicated substance so important to life. There is a great deal more to be

found out. Carotene, for example, probably has very important properties from the point of view of the nutrition of animals, owing to its relation to vitamins, as will be seen later. Not only the function of these pigments, but also much of their physical and chemical nature still remain problems of scientific inquiry.

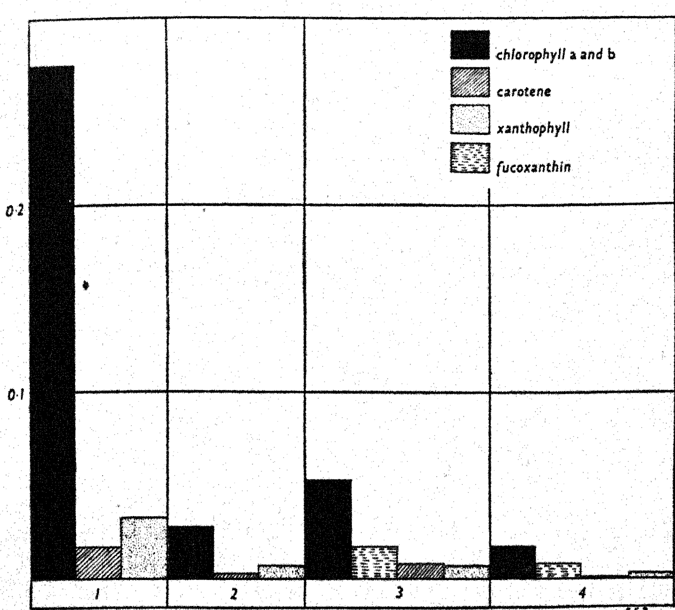


FIG. 151. PERCENTAGE COMPOSITION OF PIGMENTS IN CERTAIN PLANTS.

1, average green leaf; 2, green seaweed (*Ulva*); 3, brown seaweed (*Fucus*); 4, brown seaweed (*Laminaria*).

Chlorophyll is the basis of the manufacture of food from the raw materials, that is, the process of photosynthesis; but many other conditions are necessary in order that photosynthesis may take place satisfactorily.

The Photosynthetic Process

The fundamental facts governing the process of photosynthesis are these: water passes into the roots of a plant through its

roots. Eventually this passes up through the xylem and gets into the cells containing chloroplasts, chiefly the palisade cells. Simultaneously, carbon dioxide present in the atmosphere passes into the same cells, by entering through the stomates, passing along the air spaces of the mesophyll, and hence into the cells in solution in water. Thus the three necessary elements are supplied. Carbon dioxide contains the element carbon which is required, and the water supplies the elements hydrogen and oxygen. As has already been seen, these are all the elements that are required for the making up of carbohydrates such as sugar and starch The plant, given the raw materials, and good conditions, such as light, chlorophyll, etc., can manufacture all manner of food substances by this wonderful process of photosynthesis.

Photosynthesis undoubtedly involves many chemical reactions, so far unknown. Water and carbon dioxide are taken into the plant. From this, simple carbohydrates are built up. From these simple carbohydrates, more complex ones like starch are then manufactured. So also are fats and proteins; but one comes to still more mystery, for it is quite likely that the manufacture of one food from another does not necessarily require chlorophyll and light. Therefore, it is only safe to say that the simpler foods are *directly* manufactured by the process of photosynthesis.

For example, it is known that the starch present in the potato tuber in such great quantities is manufactured in the tuber *itself*, though, of course, not from the *raw* elements. This is quite clear when we realise what we have already learned about the passage of foods within the plant. The food-stuffs pass down through the sieve tubes, but only in solution. It therefore cannot pass down as starch, since this substance is insoluble in water.

Actually, the food passes from the potato leaf in the form of soluble sugar. When it gets into the tuber it is, therefore, converted into another food, starch, *without* the agency of photosynthesis. That is one example of many, in which one food can be converted into another without the help of photosynthesis. But it must be remembered that a food can only be manufactured, in the *absence* of photosynthesis, *from another food*. It

can never be manufactured directly from the raw materials. The mechanisms which are involved in the change of one food into another will be considered at the end of the chapter.

By taking in water and carbon dioxide for photosynthetic purposes, the plant takes in more oxygen than it needs. Therefore, during the processes involved, oxygen is given off. Thus, during the day, carbon dioxide is absorbed from the atmosphere through the stomates, and oxygen is passed out into the atmosphere. Now, as is well known, oxygen is necessary to all forms of life, both plants and animals. On the other hand, to animals especially, carbon dioxide is unhealthy. In this way, photosynthesis proves itself again to be a very useful process, since green plants, besides being the fundamental agents in the manufacture of food for all living things, help very much in keeping the atmosphere pure by absorbing the unhealthy carbon dioxide and emitting the oxygen, so necessary for breathing and other purposes.

The observation of this interchange of gases between plants and the atmosphere formed the beginning of the study of photosynthesis in the eighteenth century. It began with **Joseph Priestley**, the well-known eighteenth-century Non-Conformist minister and chemist, who did so much work on 'dephlogisticated air' (oxygen).

During some of his wonderful experiments on air, in 1771, Priestley made a remarkable discovery concerning the gases given off by plants. He observed that if a mouse be placed under a bell-jar, it finally died. That was because it used up all the available oxygen which it needed for breathing and also gave off, while breathing, carbon dioxide, which is poisonous and therefore helped to kill it. Then he placed under the bell-jar, with a mouse, a vessel containing a sprig of mint. In these conditions the mouse continued to live. He concluded from this experiment that the mint must give off 'dephlogisticated air,' which, of course, allowed the mouse to continue to breathe. The mint not only supplied the extra oxygen for the mouse to breathe, but it also absorbed the suffocating carbon dioxide, thus prolonging the animal's life.

Conditions necessary to Photosynthesis

Several important conditions are necessary for the process of photosynthesis to take place. For example, a definite amount of **chlorophyll** is essential.

Carbon dioxide, too, is clearly necessary. The amount present in the atmosphere (3 parts in 10,000) is quite sufficient for the process. If more is artificially added to the atmosphere, it actually will increase the rate of photosynthesis. The increase in carbon dioxide is advantageous only up to about 10 per cent., for if carbon dioxide is added to a percentage beyond that it begins to have a poisonous effect upon the plant, which soon dies. It has been shown that the amount of carbon dioxide in the air has a limiting effect on the photosynthetic activity of wheat. Therefore, wheat does not build up so much food as it might. Wheat plants get enough sunlight to use up *all* the available carbon dioxide by the time that the light has reached about a quarter of its average daylight intensity. Therefore, *from the point of view of photosynthesis*, three-quarters of the light on a bright day is unnecessary. Of course, this only applies to wheat; in other plants the fraction of light used may be smaller or it may be larger.

A good supply of **water** is also another essential condition for the process. Under normal conditions, of course, this is possible. But the effect of water supply is much more complicated than one would at first imagine. Naturally, the conclusion is that water is required because it is one of the essential raw materials from which the food is made. Actually, however, this is not all. As a raw material, it may be said that water is a chemical necessity. But it is also a physical necessity, for this reason: the photosynthetic cells cannot carry on their function of food manufacture unless they are in the turgid condition, and, as has already been shown, a plentiful supply of water is essential in order that the cells may be kept turgid.

A good **temperature** is also an essential feature of the process. Plants, like all living things, can only live within certain limits of temperature. Beyond 35° C. the normal plant cannot live. It is usual for an increase in temperature to cause an increase in

the rate of photosynthesis up to about 25° C. Up to this limit, the rate of the process is about doubled for every increase of 10°. Beyond that limit, the process falls off.

Light, too, is essential for photosynthesis, for the process is concerned with absorbing the radiant energy of the sun. A good light intensity is best, and that is why most plants thrive better in plenty of sunlight rather than in subdued light.

There are several other conditions which affect the process of photosynthesis; but the ones which we have considered are sufficient to give us some idea of how much this process depends upon certain conditions. All living processes are like that. They all must be subjected to certain conditions, in order to carry on.

Knowing such conditions is a great help in the cultivation of plants and also in understanding why plants behave differently in different parts of the world. For example, the conditions governing photosynthesis help, in part, to explain why the vegetation of the tropical forests is so luxuriant, and why the plants individually are usually so well developed. There, the sunlight is so much in excess of that of temperate regions, and increased light intensity gives an increase in the process. There is, too, a plentiful supply of water; but, best of all, of course, there is a very satisfactory temperature.

These conditions also partly explain why many green plants must be grown in such a position that they get the maximum sunlight. This is usually on a sloping land facing south, in the northern hemisphere: if they are grown on land facing north, there are two adverse factors brought in, namely, a reduction in light intensity and a reduction in temperature owing to exposure to the cold, northerly winds.

Such conditioning factors also explain why green plants cannot be grown indefinitely in the dark. Closely connected with this is another interesting fact. The process of photosynthesis depends upon light in two distinct ways. One has already been seen in that it does not matter if all other essential conditions, including the presence of chlorophyll, are there; if light is not present, the process cannot take place. The other is just as important in that, if there is no light, the plant cannot *make* its chlorophyll, which is so necessary. That is, light is essential for

the *manufacture* of chlorophyll, as well as for the *activity* of the chlorophyll. That explains why bulbs, when they are allowed to shoot in the cellar during the winter, show a sickly yellow shoot; but a few days after they have been exposed to the light, the shoots turn green. Again, if a stone or a plank of wood be placed on a lawn and left for a few days, when it is lifted up again the grass beneath it will be seen to have turned a yellowish colour. This gives some idea of the importance of light to the well-being of all life on the earth.

Products of Photosynthesis

The products of photosynthesis are many and varied. But they are not all made *directly* by the process. Probably the first to be made from the raw materials is glucose, a carbohydrate. After this stage, photosynthesis itself perhaps plays no further part. From the simple foods made in this way, all the other foods, such as cane-sugar, starch and the proteins and fats, are built up by the mysterious activity of protoplasm.

All plants do not make *all* forms of foods. For example, some plants make a large amount of fat, others proteins, chiefly for storage, as was seen in Chap. VI. Many, such as the potato, bean, *Hydrangea*, etc., manufacture starch. On the other hand, some, such as the onion, hyacinth and iris, never manufacture starch.

The paramount importance of chlorophyll as a source of energy can scarcely be overestimated. It was certainly the key to coal production in the distant past; it probably was the key to oil production as well (see Chap. XIII); yet little really is known of the physical and chemical nature of chlorophyll and its photosynthetic activity. Nevertheless, work on this problem is still going on in Great Britain and other parts of Europe, and in the United States.

Enzyme Action

The next question is: how do plants manufacture one food from another? This brings up a very important question, for, as has already been seen, once photosynthesis has made the simpler foods, it is probably no longer necessary for the building

up of more complex ones. Therefore, it is possible for animals, as well as plants, to convert one food into another. This ability to convert food is peculiar to all living things, and therefore involves many questions of the utmost importance.

It is all a question of chemical action and reaction. For example, starch can be converted into the sugar, glucose. It is a very complicated process and takes place in several stages ; but the two chemicals that are required to react are just water and starch. Given these two substances, they will react together and produce glucose. Nothing else is *essentially* required. Therefore, if some starch be placed in water and left for a time, glucose will be produced. But this is a very slow process, and if a tumblerful of the mixture were left for weeks on end, at the end of that time there would be not enough glucose present to cause any perceptible sweetening.

This would be far too slow for a plant or an animal : so the question is : how do living things speed up such processes ? Well, how are chemical processes accelerated in the laboratory ? For example, oxygen can be prepared by simply heating potassium chlorate ; but this is a slow process, so some manganese dioxide is usually added, and, although at the end of the reaction all the manganese dioxide is still present, the reaction has taken place at a very much quicker rate.

So also can the conversion of starch and water into glucose be made to take place at a speed many hundreds of times greater than it normally would. This is done by adding a few drops of hydrochloric acid, or almost any other acid, and heating it. But the acid is not used up in the reaction.

This speeding up of chemical actions by adding a certain substance is called **catalysis,** and the substance which is added, but not actually used up, is called a **catalyst.** Therefore, the manganese dioxide and the acid in the above two reactions are catalysts.

Now plants and animals have many such catalysts present in their bodies, usually in their protoplasm, since such catalysts are produced by the protoplasm. They are not simple substances like hydrochloric acid, but very complicated substances, probably of the nature of proteins. They are called **enzymes.** They

are very often specific for a certain reaction, that is, they will hurry up one reaction, but not another. For example, the enzyme present in plants which helps in the splitting of starch into sugar will not help, in any way, the splitting up of a fat or a protein. Therefore, for all the living processes going on in the cell, many of which involve the chemical change of one substance into another, there must be many different enzymes.

There is one very good example of the action of enzymes in the human body, namely, that of food digestion. The chief foods which we eat are carbohydrates, proteins and fats. Now, these have to be got right into our system, and passed throughout it. This is done by means of the blood stream. The food passes from the mouth into the gut, then it has to be absorbed through the walls of the gut into the blood vessels. In order to do this, it has to pass through several layers of cells. Of course it can only do this in solution. This is easy enough for such substances as sugars, for they are soluble in the water ; but for insoluble foods such as starch, fats and nearly all proteins, it is a different matter. Since such foods are not soluble, they must be made soluble first, and this is done by the so-called digestive juices containing enzymes which convert the insoluble foods into soluble ones.

Plants, too, contain many enzymes for the conversion of one food into another. Only a few can be considered, however.

Lipase is an oil-splitting enzyme. It converts fats into soluble substances. Naturally therefore it is present in the plant cell for the purpose of helping the various chemical life reactions where fats are involved. Just as one would expect, this enzyme varies in quantity, and is present in larger quantities where fats occur in abundance. For example, the seeds of *Ricinus*, the castor-oil plant, store the oil in great quantities. Lipase, therefore, is very much in evidence in the living cells of such seeds.

Diastase is a very important enzyme which is responsible for the splitting up of starch into sugar in plants. Now this process of starch disintegration is a very complicated one and takes place in several stages ; therefore, diastase, in order to help the various stages, is probably actually a mixture of enzymes rather than a single one. It is present in all leaves which manufacture starch during photosynthesis, and also in other plant organs

where starch is found, especially starch-storing organs such as the potato tuber.

It has been found that the tuber of Jerusalem artichoke yields excellent sugar from the starch it contains, by the action of diastase. Trials are still being carried out on it and, if favourable, this plant may be extensively cultivated in Ireland for the purpose. The leaves, too, make good food for farm animals.

Just as there is a large number of proteins, so also is there a large number of enzymes which assist in their disintegration. They are of very wide occurrence throughout both the plant and the animal kingdoms. A general name for the whole group is **proteases**.

There are thousands of chemical processes taking place within all living plants and animals. The majority of these take place within the living protoplasm of the cell. Also, there are many which are special to a certain plant, with the result that such a plant contains a special chemical. Nearly all the chemical reactions thus connected with life, whether general or special, are usually assisted by the presence of enzymes. Therefore, enzymes are not used only for the breaking up of complicated food-stuffs into simpler, soluble forms.

For example, the yeast plant contains a very specialised enzyme, **zymase**, which causes what is called **fermentation**, that is, the reaction of water with sugar to form carbon dioxide and ethyl alcohol (see Chap. XIII).

Another example is the enzyme called **rennin**. This enzyme aids the curdling process in milk, and is therefore of commercial importance. For this purpose it is extracted from the gastric juice of calves, and very often is referred to as **rennet**. Now, if milk be allowed to stand for some time, it will go sour and gradually curdle. Thus cheese is produced. The liquid left from the curd is called **whey**. But this natural process is not a satisfactory one, since the curd does not separate very well from the whey. Therefore, by the addition of the enzyme rennin, the separation is more complete and better cheese is assured.

An important group of enzymes are those which are connected with the various processes of oxidation which take place in living organisms. This group of enzymes is called **oxidases**.

The turning brown of the cut surface of an apple is due to the exposure of the oxidising enzymes in the cells, which then accelerate certain chemical reactions resulting in the production of the brown material. Many fruits cut up for salads, etc., turn dark like this. The colouring can be prevented by sprinkling lemon juice over the cut surfaces, since the acid lemon juice inhibits the action of the oxidases.

Reversibility of Enzyme Action

The action of enzymes is often **reversible.** This means that an enzyme can not only convert one compound into another, but it can also build up the former compound again. Thus, diastase is capable of aiding the conversion of starch into glucose ; also it can aid in the building up of starch from glucose. This underlies the processes in the potato plant which give the tubers their high starch content. Starch is manufactured in the potato leaf by photosynthesis. By the activity of diastase in the leaves, the starch is converted into glucose, so that it can dissolve in water and pass down through the sieve tubes to the tuber. This usually takes place at night. Then more diastase, present in the parenchymatous cells of the tuber, build up the glucose again into starch, by a reverse process, so that it can be stored in its insoluble form.

Anti-enzymes

Enzyme action, though it is very useful and, in fact, necessary to all living things, could also prove a great evil in other cases. For example, since meat is digested in the gut of the animal, by certain digestive enzymes which have already been considered, why do not these same enzymes help in digesting the very gut itself, since the gut is composed of substances similar to the food being digested ? This adverse effect of the enzymes, however, is prevented by the presence of other complicated substances called **anti-enzymes,** which stop the action of enzymes. The anti-enzymes, in this case, are in the cells of the gut, so that while digestion can take place in the tube of the gut, in the wall itself it is quite impossible.

PRACTICAL WORK

1. Make a rough extraction of chlorophyll from green leaves. Thin leaves should be chosen, such as those of *Tropæolum* or *Fuchsia*. First of all, kill the leaves by immersing for a few minutes in boiling water. Then place a large test-tube, about half full with ethyl alcohol, in a vessel containing water which has just been boiled, but be sure that the burner has been removed. Immerse the killed leaves in the alcohol. Note how the leaves

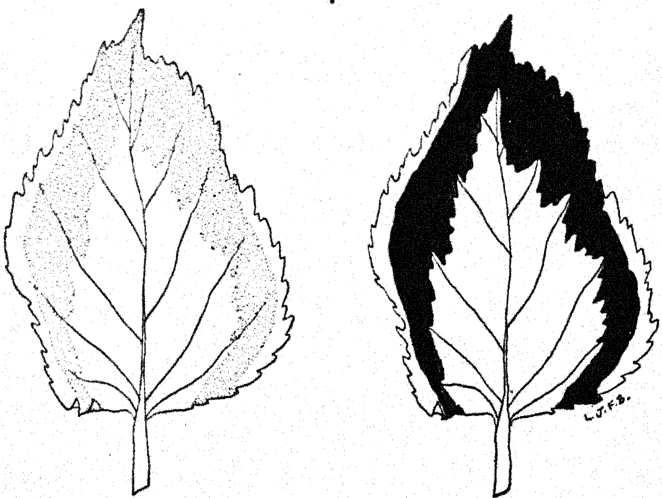


FIG. 152. EXPERIMENT TO PROVE THAT CHLOROPHYLL IS NECESSARY FOR PHOTOSYNTHESIS.

On the left, a variegated leaf, showing the green part (shaded) and the white part (unshaded); on the right, the same leaf after the iodine test for starch, showing the area which has reacted positively (black) and the area which has reacted negatively (white).

gradually lose their colour owing to the alcohol dissolving the chlorophyll. Write a description of the experiment, fully explaining all the steps taken and the results obtained.

2. Make an extract of chlorophyll in acetone from nettle-leaf powder. Prepare the leaf powder in the manner described in the text, then place some of it in a funnel fitted with a filter paper. Slowly add the acetone and collect the filtrate in a beaker or test-tube. The filtrate is an acetone solution of almost pure chlorophyll. Describe the experiment and results, and fully describe the fluorescence

as seen by looking through the solution held against a dark background.

3. Show that some green leaves are capable of manufacturing the carbohydrate starch, by means of photosynthesis. Choose a leaf of the potato, *Fuchsia*, or lilac and treat it as in Experiment 1,

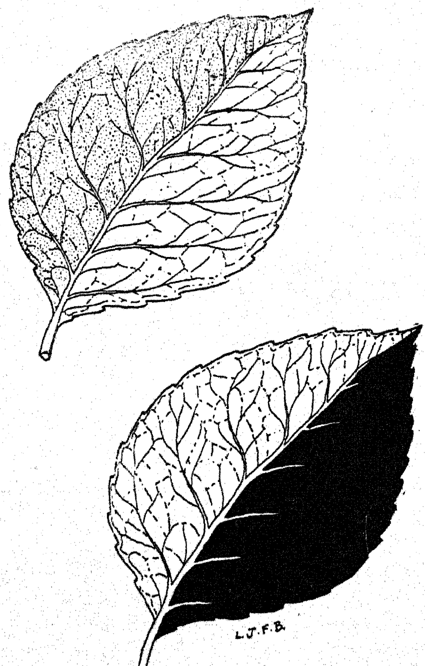


FIG. 153. EXPERIMENT TO PROVE THAT A CERTAIN CONSTITUENT OF THE AIR IS NECESSARY FOR PHOTOSYNTHESIS.

Above, a leaf with part of its surface smeared with vaseline (shaded); below, the same leaf after the iodine test for starch, showing part which has reacted positively (black) and part negatively (white).

until it becomes whitish through loss of colour. Then subject it to the iodine test for starch. Perform a similar experiment, using onion or hyacinth leaves.

Record this experiment and account for the results.

4. Prove that chlorophyll is necessary in order that photosynthesis may take place. Perform an experiment similar to

Experiment 3, choosing some type of thin variegated leaf. In this type of leaf, there are certain areas green with chlorophyll and others devoid of chlorophyll (Fig. 152).

Note that the green areas give a positive starch reaction, whereas the white areas react negatively. Record and explain these results.

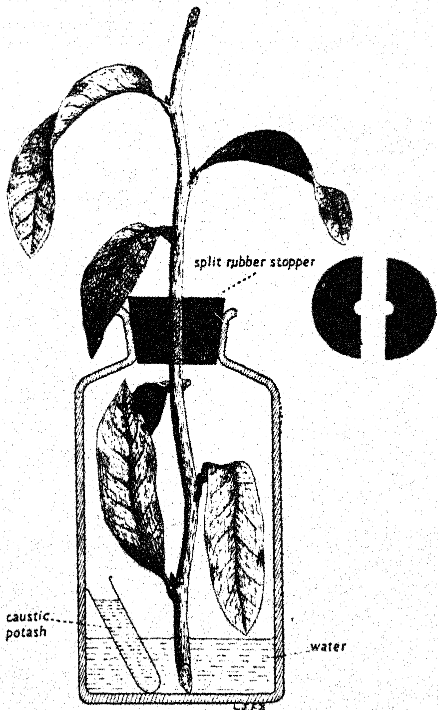


FIG. 154. EXPERIMENT TO PROVE THAT CARBON DIOXIDE IS NECESSARY FOR PHOTOSYNTHESIS.

On the right, the plan of the rubber stopper to show how it is bored and split before use.

5. Prove that a certain constituent in the air is necessary for photosynthesis. Choose a green leaf (do not remove it from the plant) and smear some vaseline over a portion of its area (Fig. 153). Do this on both sides of the leaf, making the areas coincide with each other. Allow the leaf to remain in such a condition for about two days, then take it off the plant and remove the vaseline.

Subject the leaf to the iodine test for starch. Record and explain the results obtained.

6. Prove that the constituent of the air necessary to photosynthesis is carbon dioxide. Fix up the apparatus as shown in Fig. 154. Make sure that the rubber stopper is fixed firmly, and smear vaseline over the surface of the stopper to prevent any air entering the vessel either between the stopper and the neck or the stopper and the plant stem. Place the apparatus in a warm room near the window, or under any conditions such that photosynthesis can take place freely. Leave for two or three days, then perform the iodine test for starch on a leaf from that part of the twig inside the vessel and also a leaf outside the vessel.

Realising that caustic potash absorbs carbon dioxide rather freely, fully explain the results obtained.

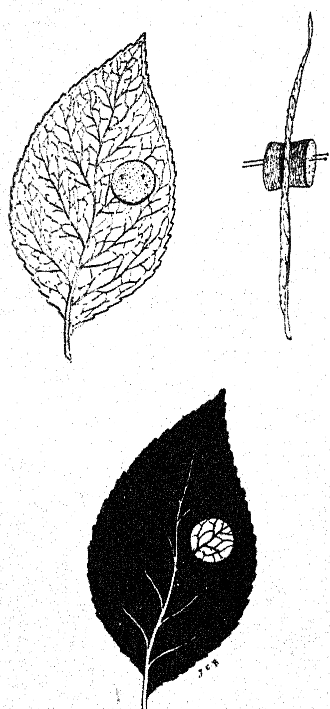


FIG. 155. EXPERIMENT TO SHOW THAT LIGHT IS NECESSARY FOR PHOTOSYNTHESIS.

Top left, a leaf, a portion of which is covered by two corks fixed with pins; top right, side view. Below, the same leaf, tested for starch twenty-four hours afterwards.

7. Show that a good supply of water is necessary for photosynthesis. Place a potted plant in a dark room for forty-eight hours, so that at the end of that time there is no starch present in the leaves. Then remove two leaves. Stand one in water and place in the light; put the other in the light too, but do not supply it with water. After about eight hours, test both leaves for starch. Record and explain the results obtained.

8. Show that light is necessary for photosynthesis. Choose two small corks equal in size, and by means of a couple of pins, fix them opposite each other on the surfaces of a leaf as shown in Fig. 155, taking care not to crush the tissues of the leaf. Do this without removing the leaf from the plant. After about twenty-four hours and towards the end of the day, remove the leaf and test it for

starch by means of the iodine test. Make a drawing of the result and explain it.

9. Show that green aquatic plants carry out photosynthesis. There is normally sufficient carbon dioxide dissolved in water to supply such submerged plants. Choose some fresh, green Canadian pondweed (*Elodea canadensis*) and place it in the apparatus

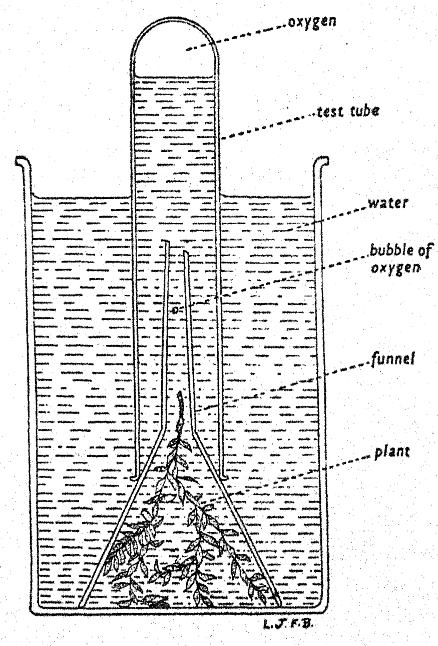


FIG. 156. EXPERIMENT TO DEMONSTRATE PHOTOSYNTHESIS IN AN AQUATIC PLANT.

N.B. This apparatus is more easily assembled completely under water.

as shown in Fig. 156. The apparatus should be set up completely under water, in a sink or bucket. Then, when it is removed, the test-tube is full of water. Place the apparatus in bright sunlight. Notice that small bubbles are given off periodically at the cut ends of the pondweed and collect in the top of the tube, gradually displacing the water. When a sufficient supply of the gas has been collected, remove the test-tube and test the gas with a glowing splinter. The gas proves to be oxygen.

Describe the experiment fully, and explain why the gas collected is oxygen.

N.B.—This is a difficult experiment to perform unless good fresh sprays of the plant are chosen, and it is a bright, warm day.

10. Demonstrate the activity of the enzyme diastase. Germinate about a hundred barley grains. When the roots are about one inch long, grind the whole of the seedlings in a mortar. Then boil enough starch to cover a sixpence in a little more than a cupful of water. Allow this to cool until it is about lukewarm.

Barley seedlings contain diastase, therefore the extract of the seedlings obtained in the mortar contains this enzyme. Add all the extract to the starch paste and keep the whole just lukewarm.

Test this mixture at frequent intervals for starch, by adding iodine solution to a drop of it. Keep a record of these results. After a time, no positive reaction occurs, thus showing the absence of starch. Then test the whole solution for sugar by means of Fehling's solution.

Discuss these results.

CHAPTER XII

TRANSPORT OF WATER AND FOODS WITHIN THE PLANT

It is very common in greenhouses in the early morning, and especially when it is very cold outside, such as during frosty weather, to find that the inside surfaces of the glass walls and roof are covered with water. A similar effect can be obtained by placing a potted plant, bearing plenty of green leaves, beneath a glass pot or bell-jar. After a few hours, it will be seen that water is being condensed on the inside walls of the jar. This is because water is being given off by the plant. We cannot see the process taking place because the water is being given off, chiefly from the leaves, as water vapour. Then, when it comes into contact with the cold glass surface, it is condensed into liquid water.

This process of giving off water into the atmosphere by plants is called **transpiration.** All terrestrial plants (that is, plants which grow in the soil, as opposed to water plants) **transpire.** An oak tree may give off 150 gallons of water in one day. The process, unlike that of photosynthesis, takes place night and day, but at varying rates.

Transpiration Stream

It has already been seen that the origin of the water in a plant is the soil. It is clear, therefore, that there must be a passage of water from the soil, through the roots, into the stem, up through the vessels in the stem, into the leaves, and hence out from the leaves into the atmosphere as water vapour. This stream is a constantly flowing one, and is referred to as the **transpiration stream.**

It is quite clear that *all* the living cells of the plant need a plentiful supply of water. The amount of water absorbed in a

few minutes by the plant, from this point of view, however, should satisfy it for several hours, so why is the passage going on continually ?

The water absorbed from the soil is not pure. It is essential to the plant that it should contain certain mineral salts for the sake of the plant's nutrition. Now, the amount of nutrient salts in soil water is very small. Therefore a considerable amount of the soil water is required in order to supply a sufficient amount of dissolved salts. This, therefore, is one reason why so much more water is taken in by the plant than is actually required. Another reason is that all the living cells in the plant need to be constantly irrigated with fresh water in order to carry on their life processes. If they are not well supplied with water, there is a risk of the cells becoming plasmolysed, and then they cannot perform their functions to the best advantage.

Apart from all this, however, it is necessary that there be a constant stream of water taking place within the plant. This stream must go, not only in an upward direction from root to leaves, but also in a downward direction. Water must also pass out constantly to all branches and the various plant organs, and back again.

Such a stream is necessary in order to carry all the various food and other substances which the plant requires in its various parts. For example, the green leaves themselves require water as a raw food material, and they also require the mineral salts which are dissolved in that water ; hence the upward stream of water from the roots, through the vessels of the xylem. Then, all the living cells, even in the lowermost parts of the roots, especially the actively growing cells, must have manufactured foods ; hence the downward passage of water, containing the dissolved food substances, through the sieve tubes of the phloem.

Consequently there is a continual stream of water passing throughout all the plant tissues, acting as a kind of canal system for conveying the various substances within the plant from one part to another. This is similar to the blood stream in animals, with the exception that the same blood is being utilised over and over again. If extra blood is needed it is manufactured by the

animal itself, chiefly by means of the liver, whereas the water in the plant is constantly being given off by the leaves and just as constantly being renewed from the soil.

Evaporation and Transpiration

The general structure of leaves offers a splendid mechanism for evaporation of water, which is the fundamental basis of transpiration. From the walls of the cells of the leaves the water evaporates into the atmosphere.

This evaporation can take place, of course, by two routes, through the stomates or through the cuticle which covers the epidermal cells. Now, the cuticle is composed of substances related to fats, therefore it will not allow water to pass through it easily. Yet, in spite of this, a little evaporation does take place through the cuticle. This is called **cuticular transpiration.** But by far the majority of the water is transpired through the stomates. This is called **stomatal transpiration,** and accounts for 80 to 97 per cent. of the normal plant's water loss. There are exceptions to this, however ; for example, in the tropical rain forests, where there is always a plentiful supply of water, the plant can afford to transpire almost any amount. Here, therefore, cuticular transpiration is almost equal to that of stomatal.

Action of Stomates

The mesophyll cells of the leaf abut on to air spaces. Water passes through these cells, and on the outer walls of the cells it forms a thin film exposed to the air spaces. Here it evaporates into the spaces, and then it passes through the stomatal pores.

Now, if these pores were all fixed in size, the plant would have no control over the amount of water which it would lose by transpiration. But, as it happens, the plant can control the size of the pore of the stomate to a certain extent. This is done by the motion of the guard cells which surround the pore. Each guard cell is capable of moving slightly towards the other, and thus nearly closing the pore. It is also capable of moving away, thus opening the pore.

Naturally, certain conditions sometimes arise when the plant is experiencing difficulty in getting a sufficient water supply, for example, during a period of drought. In those circumstances, the guard cells of the stomates move towards each other, thus

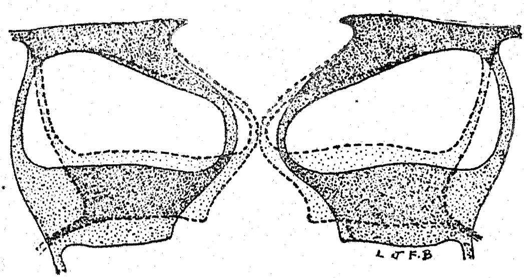


FIG. 157. DIAGRAMMATIC REPRESENTATION OF THE ACTION OF GUARD CELLS.

The deeper shading indicates the position of the guard cells when the stomate is open, and the lighter shading their position when the stomate is closed.

closing the pores. In this way, loss of water by transpiration is very much reduced. If, on the other hand, a plentiful supply of water is available in the soil, the guard cells move away from each other, thus opening the pores to their utmost capacity (Fig. 157).

Conditions affecting Transpiration

Just as certain conditions affect the rate of the evaporation of water in ordinary circumstances, so does the process of transpiration depend on certain conditions. These are very important, especially to the gardener and farmer.

One very important condition is the humidity of the atmosphere, for water evaporates at a much greater rate in a dry atmosphere than it does in a very humid one. When the air becomes very dry, therefore, the stomates reduce the size of their pores by the action of the guard cells.

A very potent factor in governing plant transpiration is wind. Evaporation is greatly enhanced by wind. This condition is also bound to affect transpiration from the plant leaves. In

exposed places, therefore, plants are liable to suffer from excessive transpiration due to exposure to the wind. Gardeners take this into consideration very often by planting delicate and susceptible crops near high walls, where they will be sheltered from the winds. High hedges, too, on cultivated agricultural lands have a similar effect in protecting the young crops from excessive wind action. Very often, gardeners actually protect their crops from excessive transpiration due to wind by fixing up 'wind-breaks' on the windward side of the crops. These breaks are usually made of reeds or branches. This is a very common sight in that part of France where the well-known piercing and bitter wind called the *mistral* sweeps down to the Gulf of Lions.

Light also affects transpiration in that it increases the process. Therefore, transpiration takes place at a greater rate during the day than during the night.

The water absorbed which does not finally pass out by evaporation can be accounted for in several ways. Some passes into living cells, on the way up, to take part in the many chemical processes in those cells. Some is used in the chemical processes involved in photosynthesis, which is going on in the chlorophyll-containing cells. A large quantity goes to form the downward current in the sieve tubes of the phloem, thus acting as a conveyor of food and other substances throughout the plant.

Mechanism of the Transpiration Stream

Now, equally as important is the problem of how a plant manages to get the water to its highest leaves. It does not matter so much in the case of a low-growing plant; but in the case of trees which grow to a height of several hundreds of feet, what are the forces which send the water from the soil right up to the leaves at the very top?

This is a problem which is still awaiting solution. Many suggestions have been made throughout the history of the study of the subject; but not one has been actually proved. There is one suggestion, however, which seems to explain the phenomenon better than any others.

All chemical substances are composed of molecules. If two

molecules are brought close to each other, they set up a definite attraction, with the result that they tend to move towards each other. This is the case between two molecules of the same substance or two molecules of different substances. For example, two molecules of water exert an attractive force between each other, which tends to bring them together, also a molecule of water and one of, say, carbon dioxide exert an attraction. The attractive force exerted by two molecules of the *same* substance is called **cohesion**; whereas that exerted by two *different* substances is called **adhesion.**

Cohesion is usually stronger than adhesion, in normal circumstances. This explains why a drop of water usually remains intact. All the molecules of the water are attracted to each other by the force of cohesion, with the result that the drop remains as one whole. Cohesion between molecules of a gas is less strong than that between molecules of a liquid. On the other hand, cohesion in a solid is greater than that of a liquid.

In the transpiration stream of a plant there is water stretching in a column from the roots, through the vessels of the stem up to the leaves. This column is constantly flowing in an upward direction. The problem is to discover how this can take place without the column breaking down. In ordinary circumstances, water would not remain as such a high column, for its molecular cohesion is not strong enough, since it is a liquid. If it were a solid, it would do so.

Consider two columns, one a solid and the other a liquid present in a tube, both stretching the height of a tall tree, say, 250 feet. The former could be represented by a steel rod. If we took hold of this rod at the top and pulled at it, the whole length of the rod (250 feet) would be lifted with it, if we could exert sufficient strength. If, on the other hand, in the case of the 250 foot column of water, we took hold of the end of that, only the water which actually touched our hands would be lifted, merely because that amount of water had adhered to our hands. The rest would remain undisturbed.

This property is easily explained by the force of cohesion. Cohesion between the molecules of a solid is very strong. Therefore, when we catch hold of the end of a rod and pull, we cause a

certain number of the molecules to move. The molecules next to these move with them, owing to the attractive force of cohesion. For the same reason, the molecules next again move, and so on throughout the length of the column. Thus by moving certain molecules, all are moved in the same direction. In the case of the liquid column we do not get this, for cohesion between molecules of liquid is by no means so strong as it is between molecules of a solid.

These facts probably explain what we have in the transpiration stream in plants. There, it is suggested that the water column stretching from root to leaves does not act as an ordinary column of liquid, but rather as a solid column. Therefore, by forcing it to move at the upper end, the whole column moves in the same direction.

The force which causes the initial move is the evaporation from the leaf cells. It takes water away and tends therefore to drag a fresh supply of water into the leaf cells in the place of that removed. This gives an upward movement and, since the water is supposed to act as a solid, the whole column, right down to the root, moves upwards by cohesion. Evaporation is constantly taking place, therefore the upward-moving force is always present and the column of water is always on the upward move. But the column is not broken, in spite of the constant removal of water from the top, since a fresh supply is normally constantly on tap from the soil.

This theory seems quite a plausible one ; but the question is : are we justified in assuming that the water column present in a plant is so different from an ordinary column of water in that it acts like a solid rather than a liquid column ? Well, the answer to that is, that we are justified, to a certain extent, since, in certain circumstances, a column of water can be made to act like a solid instead of like a liquid. In fact, it has been proved that in order to break down a column of pure water in a metal tube, a force equivalent to more than 3000 lb. to the square inch is required.

This, of course, is only a theory and has never been proved beyond doubt ; but it is the best one for explaining why water will rise to the top of tall trees. It is called the **cohesion theory of**

the ascent of plant sap (or water), and was first of all formulated by **Professor H. H. Dixon.**

Water Supply

From the foregoing considerations of the process of transpiration and other water relations of the plant, it is clear that in the soil there must be a certain amount of water. The limits of the water content of the soil, satisfactory to a plant under normal conditions, are wide ; but they do exist. For example, if the soil is too dry, then the plant may not be able to obtain enough water for its various life processes, or, more likely still, it will continue to lose water by transpiration and not be able to obtain enough to make good the loss. It is true that, in such conditions of emergency, the stomates can cut down the water loss by regulating their guard cells ; but this takes place only within very narrow limits. In these circumstances, the plant would eventually wilt, that is, owing to the loss of turgor in its cells, it would lose its firm texture and become flabby and, unless more water were added to the soil, the plant would finally die. Thus there is a minimum limit to the amount of water in the soil, from the point of view of plant growth.

On the other hand, there is a maximum limit. From the point of view of the water relations of the plant, too much water in the soil could scarcely do any harm, for if the plant absorbs more than it requires, it can easily get rid of the surplus water by transpiration. Also, considerations of the phenomena connected with osmosis convince us that there is a limit to the amount of water a plant can absorb in a given time. In spite of this, however, there is an upper or maximum limit to the amount of soil water where normal plants are concerned, though the limit is not connected with the plant's water relations. It is decided by several other factors.

One is fairly clear. That is, the soil must not be so full of water that it becomes water-logged. If this takes place, then all the air spaces between the soil particles become flooded with water, with the result that all the air is driven out of the soil.

Excessive Water Loss

In this problem of getting rid of excess water, or, on the other hand, of conserving its water supplies, the plant is often able to deal with emergencies, as it is in the case of other phenomena. Often, of course, the plant has to be prepared for conditions which are too dry. On the other hand, it is sometimes faced with too much water in the soil, to such an extent that it still cannot get rid of its excess water quickly enough by means of transpiration; or it may be faced with an exceedingly humid atmosphere, where, as has already been seen, transpiration is forcibly reduced in rate. In both such cases of emergency, many plants are prepared.

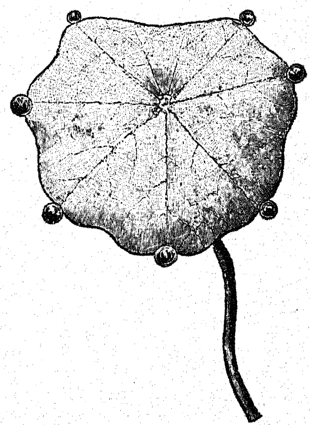


FIG. 158. EXUDATION OF DROPS OF WATER FROM A LEAF OF *Tropæolum majus*. (*After Noll.*)

Consider the too humid conditions first. Evaporation, in such cases, is not enough, so water is forced out of the leaf in the liquid state as well. This is called **exudation.**

For example, in the early morning, after a warm, very humid though rainless night, drops of water may be seen on the tips of green leaves, especially of grass leaves, in the meadows. This is often mistaken for dew. Actually, however, it is liquid water that has been forced out of the leaf. Careful examination will reveal that a drop will eventually fall off the leaf, and will gradually be replaced by a new one as more water is exuded. Similar drops of exuded water may be seen, under such humid conditions, on the blunt projections on the margins of *Tropæolum* leaves (Fig. 158). Such water may be forced through the stomates of the leaves or they may be forced through hairs present on the leaves, or through special exuding pores called **hydathodes,** which are present in certain types of leaves

(Fig. 159). Such exudation is very common from the leaves of plants growing in the humid tropical forests, giving a constant drip, drip of water. As many as 190 drops of water have been counted from one leaf in one minute.

Economy in Water Loss

The other emergency is the possibility of the surrounding conditions being too dry. Such conditions may be caused by an insufficient supply of water in the soil, or atmospheric conditions being too dry, thus causing excessive transpiration, or both. Normal plants, growing in places where the water equilibrium is

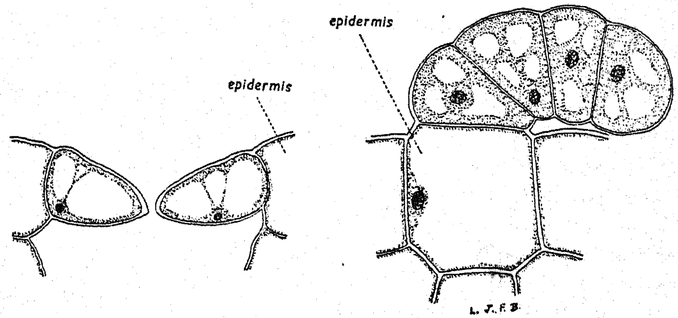


FIG. 159. LEFT, SECTION THROUGH A HYDATHODE OF *Tropæolum majus*; RIGHT, HYDATHODE OF *Phaseolus multiflorus* (SCARLET RUNNER).

seldom upset, have no redress against such conditions arising, except with the rather slight controlling influence of their guard cells. On the other hand, certain plants grow where excessively dry conditions are constantly occurring, and such plants have several devices for fighting this problem.

Many leaves are covered with a thin waxy layer, which is whitish in colour, called 'bloom'; for example, the india-rubber plant, cabbage, runner bean, sugar-cane, etc. This waxy layer clearly prevents a certain amount of transpiration, especially cuticular, from taking place.

The cross-leaved heath (*Erica Tetralix*) and marram grass (*Ammophila arundinacea*) both grow on open moors, where transpiration is naturally very high. Here, the heath leaf is folded

to form a groove, and all the stomates are present on that part of the leaf bounding the groove (Fig. 160). Thus, the stomates are protected from the excessive winds of the moors. The inner surface, where the stomates are situated, are still further protected by a growth of hairs. On the other hand, the leaf of marram grass becomes folded, with the lower surface on the inner side, thus protecting the stomates from the wind. Other moorland plants are similar in this respect (Fig. 161).

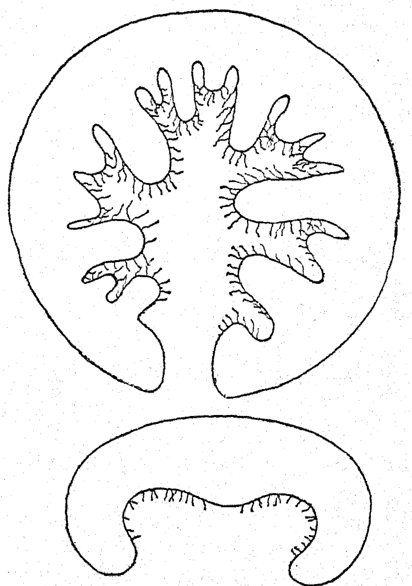
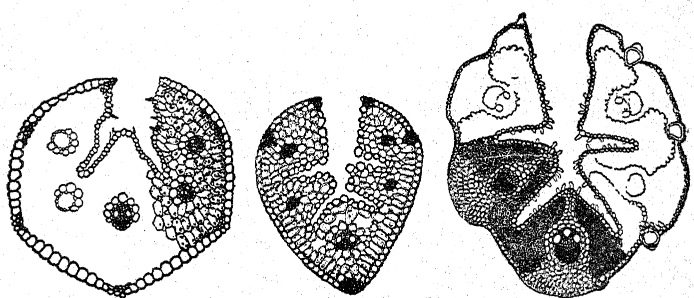


FIG. 160. TRANSVERSE SECTIONS OF LEAVES OF MARRAM GRASS (ABOVE) AND CROSS-LEAVED HEATH (BELOW), SHOWING THEIR INCURVED NATURE AS A PROTECTION AGAINST EXCESSIVE TRANSPIRATION. Note the presence, too, of protective hairs.

The bracken (*Pteridium aquilinum*) and bilberry (*Vaccinium Myrtillus*) are very interesting plants, from this point of view. Both plants will grow on exposed heaths and commons, and also in sheltered woods. The leaves of these plants on the open commons are tough and thick, whereas those of the woodlands are much finer and thin. This is because the leaves of the exposed situation have a much thicker protective cuticle, thus reducing water loss. In the case of the leaves of the woodland plants, such protection is unnecessary. Other plants, such as the mullein (*Verbascum*), cover their leaf surfaces with a growth of hairs, thus protecting their stomates from the piercing, drying winds. Many plants get over the difficulty by reducing the surfaces of their leaves to a minimum, thus reducing the evaporating surface. This is seen in the case of gorse.

Winter conditions are, to the plant, usually comparatively dry, though one would imagine the reverse to be the case. In winter, however, there is a reduction in temperature. This reduces the rate of water absorption by the root. Also, more important still, in colder climates, water is very often frozen. Then, of course, it is a solid; and since as such it cannot pass into a cell, it might just as well not be present at all, for all the use it is to a plant.

Deciduous trees prepare for the physiologically dry conditions of winter by shedding their leaves, thus getting rid of their transpiring surfaces. Evergreens prepare for such trouble by



Wavy hairgrass. Sheep's fescue. Matgrass.

FIG. 161. TRANSVERSE SECTIONS OF LEAVES OF MOORLAND GRASSES.

The upper surfaces bear the stomates, and are infolded.

(*After Miall.*)

developing thick cuticles on their leaves. This is still better seen in the case of coniferous trees such as the pines and the firs. Such trees are more at home in subarctic conditions. That is why they are found as the chief form of vegetation on high mountains and on the mountainous slopes of northern countries such as Scandinavia, northern Russia, Siberia, Estonia, and northern Canada, etc.

As is well known, most coniferous trees bear needle-shaped leaves. Thus the transpiring area is very much reduced (Fig. 32, Scots pine). But besides this, each stomate is sunk down into a pit in the tissue of the leaf. Thus, the piercing winds cannot directly hit the stomates themselves. This is seen even

better in the leaf of the Australian desert plant, *Hakea*, in which not only are the stomates deeply sunken, but also the waxy cuticle is extremely thick (Fig. 162).

Another preparation against adverse dry conditions is to absorb more water than is immediately required, when it is available in quantities, and then storing a certain amount of it;

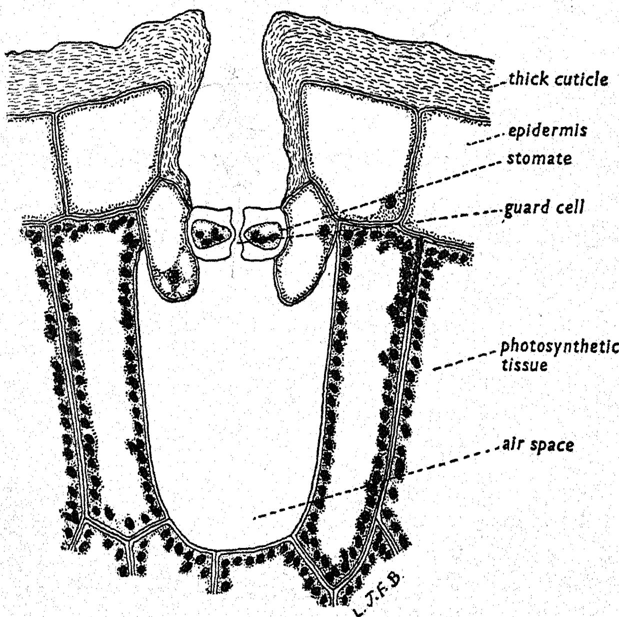


FIG. 162. SECTION THROUGH A PORTION OF A *Hakea* LEAF, PASSING THROUGH A STOMATE.
Note the sunken stomate and the very thick, waxy cuticle.

just as plants and many animals store food to tide them over bad times. This storage of water takes place in many plants. The best examples, however, are the desert plants known as cacti (Fig. 163). In such plants, the stem develops a large amount of parenchymatous cells, all of which store water. The stems thus become succulent. Transpiration is also reduced, since the leaves are often modified into mere spines, which protect the

plant against browsing animals. In Great Britain, the stonecrop (*Sedum acre*), a plant which usually grows on dry walls, stores water in its leaves, with the result that they are thick and fleshy.

Some interesting work on the water relations of the plant is being done in various centres of research, at the present time, and especially in the Union of Socialist Soviet Republics (U.S.S.R.) by Professor N. A. Maximov. For example, there it has recently been shown how the water system throughout the plant is very adequately interconnected. Many fruits, such as the orange, are succulent, thus containing a good supply of water. Now it is obvious that if a spray of leaves be cut and allowed to remain standing away from any water supply, the leaves will gradually wilt through loss of water. It has, therefore, recently been shown in Russia that if two sprays of leaves of the orange plant be taken, one bearing fruit as well as leaves, and the other bearing leaves but no fruit, and both subjected to such conditions, the leaves of the fruit-bearing spray take much longer to wilt than the leaves of the spray with no fruit. This shows that the water in the leaves need not necessarily come direct from the root. It can, if the necessity arises, be drawn from other sources in the plant; in this case, the fruit.

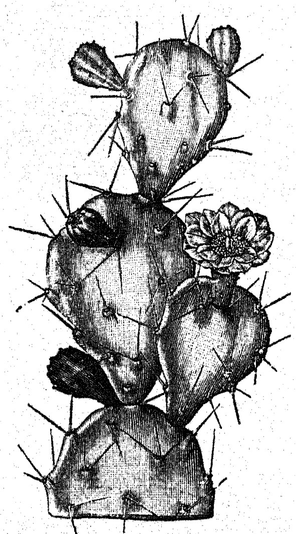


FIG. 163. PORTION OF THE PRICKLY PEAR (*Opuntia*), A DESERT CACTUS.

Note the fleshy, water-storing stem, and the leaves reduced to spines.

Transport of Dissolved Substances

Closely associated with the complicated water system in the plant, is the transportation of the substances dissolved in the water. A passage of different substances such as raw materials, dissolved foods, waste products and dissolved gases is necessary

in the complicated system making up the plant body. The means of such transport in the plant is the water system, which passes

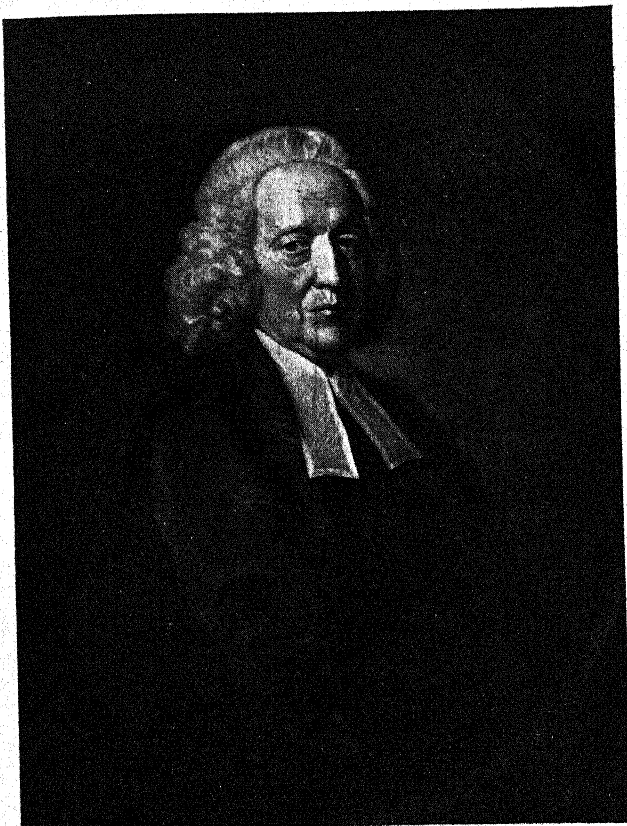


FIG. 164. STEPHEN HALES, 1677-1761.

The English curate, physiologist and chemist. He did much work on transpiration and growth in plants; and much on the physiology of animals.

upwards and downwards, and in all other necessary directions in the plant. This conveying of dissolved substances from one part of the plant to another is called **translocation.**

For example, dissolved mineral salts absorbed by the root from the soil are not required so very much by the root itself. They are required chiefly in the leaves where food manufacture is taking place. Thus they are translocated by the transpiration stream passing from roots to leaves through the wood vessels.

Again, food-stuffs manufactured by the leaves would be scarcely any use if they remained in the 'factory.' They must

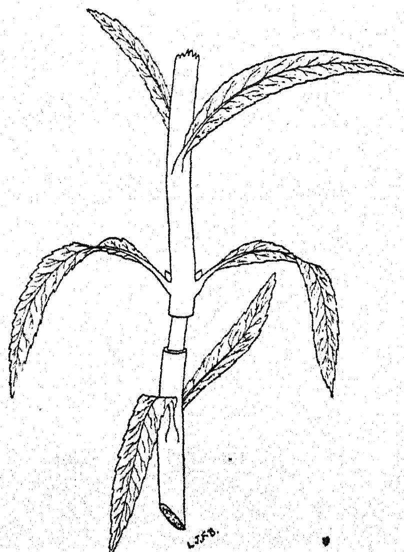


FIG. 165. A WILLOW STEM RINGED TO SHOW THAT WATER PASSES UP THROUGH THE WOOD.

pass out of the leaf, and hence to those parts which consume them. Such parts are all the living cells of the plant. Then, very often food is stored, as, for example, sugar in the vacuoles of the cells of the onion bulb, or as starch grains embedded in the cytoplasm of the cells of the potato tuber. Such foods are made soluble by enzymes in the factory (the leaf) and then translocated in a water stream down through the sieve tubes of the phloem. Then as they reach their destinations they pass across the cell-walls and thus into the cells which require them.

Much of the first work on transpiration was done by **Stephen Hales** (Fig. 164), who lived in the seventeenth and eighteenth centuries. He was really a curate, who worked chiefly at Teddington in Middlesex, though he carried out some splendid researches in plant physiology and even more important ones in human physiology. One very important experiment which he performed in connexion with plant translocation has since been called the **ringing experiment.**

For this he chose willow twigs bearing leaves. Now willow twigs easily form adventitious roots near their cut ends, when placed in water. Hales ringed some twigs, that is, cut away all the soft tissues (bark, cork, phloem and cambium) and left the wood, in one complete cylindrical area of the twig (Fig. 165). In spite of this the leaves *above and below* the ring remained fresh, thus showing that water must pass up through the wood.

But another important observation was made. In ringed twigs, where all leaves below the ring had been removed, the adventitious roots, instead of developing near the cut ends, developed just *above* the ring. Such roots require food manufactured from the leaves above, and therefore, since they developed above the ring only, this shows that by ringing the stem, the path of downward translocation of food had been removed. We now know that this is true, for it is the phloem (Fig. 166).

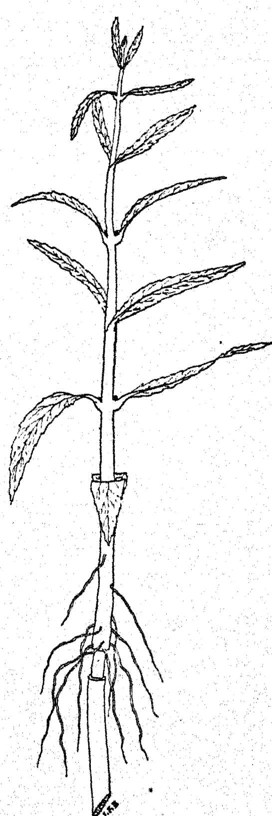


FIG. 166. A WILLOW STEM RINGED AND PRODUCING ROOTS *above* THE RING, THUS SHOWING THAT FOOD PASSES DOWN THROUGH THE PHLOEM.

PRACTICAL WORK

1. Show that water vapour is given off from the leaves of a normal green plant.

Choose a potted plant, such as that of *Pelargonium*, and cover the sides of the pot and the surface of the soil with sheet rubber. Naturally, of course, the sheet rubber will have to be slit in order to allow for the plant stem, but care should be taken that no soil surface is exposed. Then put the pot on a sheet of glass and cover it with a large glass jar or bell-jar. Seal the edges of the jar, where they touch the glass sheet, by means of vaseline. Note that after a short time, water is condensed on the inside of the jar.

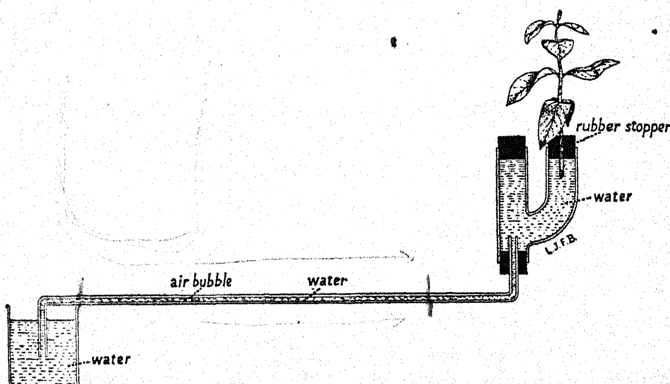


FIG. 167. A POTOMETER.

Then remove the jar and thoroughly dry the inside of it. Smear all the leaves, both upper and lower surfaces, with vaseline and repeat the experiment. Note that there is now no condensation of water.

Fully describe this experiment, explaining the reason for every step taken, and discuss the results.

2. Fix up a transpiration balance and prove that a normal plant transpires water.

Prepare a potted plant in a manner similar to that suggested for Experiment 1 and then put it on a balance. Carefully weigh the plant and record the weight. Then leave it for a few hours (there is no need to remove it from the balance) and then weigh it again. Note the loss in weight and discuss the significance of this.

3. Set up the apparatus as shown in Fig. 167.

This apparatus is called a **potometer**. The potometer tube itself is composed of two arms. The whole apparatus must be fixed up under water in a deep sink, so that when it is removed it is full of

water. Fix the potometer tube to a retort stand, or some other suitable support, and then carefully remove a drop of water from the end of the long glass tube by means of a piece of blotting paper or a small brush. Thus will a bubble of air rise into the glass tube. Place the end of the tube in a vessel of water. Allow the bubble to pass a short distance along the horizontal part of the tube, then mark its position by means of a piece of gummed paper. Dry the leaves of the shoot by means of blotting paper.

Leave the apparatus for a time, then note the position of the air bubble. Draw and describe the apparatus and explain the results.

4. Show that transpiration of water from the leaves of a plant exerts a considerable suction, which draws more water up through the stem.

Using a similar potometer tube as in Experiment 3, set up the apparatus as shown in Fig. 168. This again must be set up under water in a sink, in order that the whole be filled with water. Make sure that the various rubber stoppers are fixed water-tight. Then place the end of the tube in a beaker of mercury and support the potometer tube by means of a retort stand. Dry the leaves of the shoot by means of blotting paper.

Leave this for a few hours, and then note the results. Draw the apparatus and describe and discuss the results.

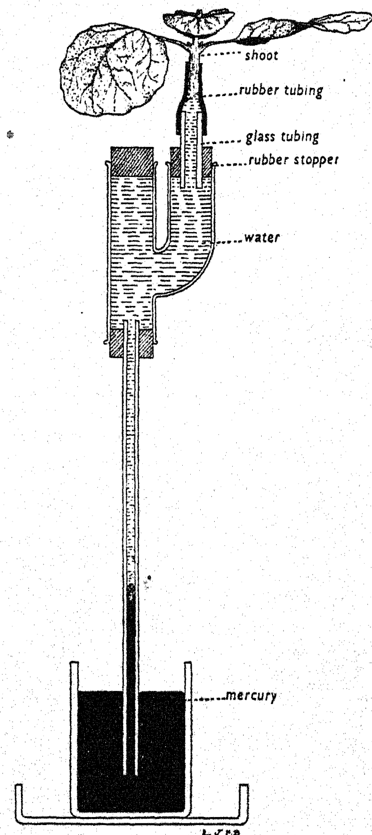


FIG. 168. APPARATUS FOR DEMONSTRATING THE SUCTION EXERTED BY TRANSPIRATION.

5. Show that transpiration takes place chiefly through the stomates of the leaves.

There are several ways of showing this, but the following two methods should be sufficient :

(*a*) Choose four similar leaves of the same plant, such as

Hydrangea, *Fuchsia*, elder, etc. Then treat them in the following manner:

(1) Smear both surfaces completely with vaseline.
(2) Smear the upper surface only with vaseline.
(3) Smear the lower surface only with vaseline.
(4) Leave untouched.

Then suspend the four leaves from a piece of wood by means of drawing pins through the leaf stalks, thus allowing the leaves to hang freely exposed to the air.

After a day, record the results, noticing chiefly to what extent wilting has taken place in each leaf. Explain the results.

(*b*) Make a solution of cobalt chloride. Dip some pieces of filter paper in the solution, then dry them in a warm oven. Notice that, when dry, they are blue in colour. Dip one in water and notice that it turns pink.

Now choose a thin leaf and cover each surface with a cobalt chloride paper, thus making a sandwich. Hold the sandwich steady between two small sheets of perfectly dry glass and watch the results.

The cobalt chloride paper covering the lower surface of the leaf will turn pink to a greater extent, and also more quickly than the other. The main veins of the lower surface, too, will be traced out, in that their traces will remain blue.

Fully discuss these results.

6. Examine the effects of various conditioning factors on transpiration.

Set up the apparatus as shown in Fig. 169; again this must be done under water for the same reasons as before. Make sure that both ends of the pressure tubing are water-tight by means of some wire, but do not draw the wire too tight at the stem end, else the stem itself will be crushed. Then by means of a pipette, pour a little oil (olive oil will do) on the surface of the water in the tube, to prevent evaporation from the surface. Dry the leaves of the shoot by means of blotting paper.

Set up four experiments in this way. Then weigh them all separately and record the weights. Afterwards place one in a light room; another in a dark room; another in a light room near an electric fan, which will cause a wind; and the last in another room at a higher temperature, recording the temperature.

After about twenty-four hours (making sure that the same length of time has been allowed in all four cases), weigh them all again, and calculate the loss of water from each, due to transpiration. Then in each case, remove all the leaves and trace their areas on squared paper. By counting the squares, the area of transpiring surface on each shoot used can thus be estimated. From this, calculate the amount of water transpired from a unit area (say, one square centimetre) in each case.

Thus the comparative rate of transpiration can be obtained for a

normal plant, a plant in the dark, a plant in the wind, and finally a plant subjected to a higher temperature.

Fully describe this experiment and record the results. Discuss the significance of these results.

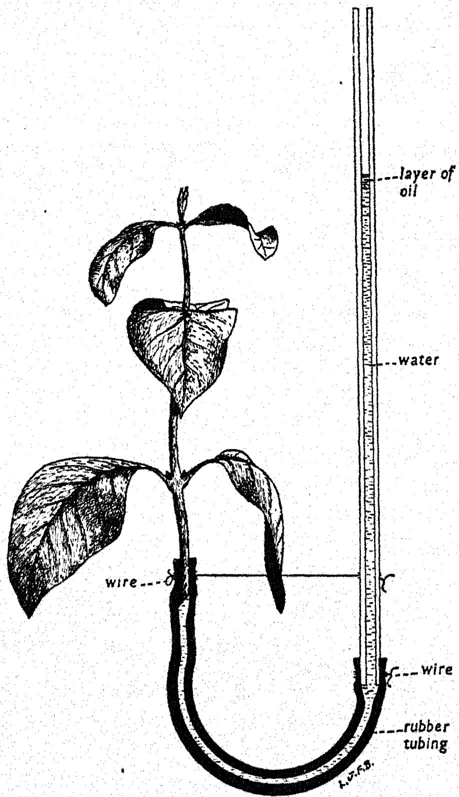


FIG. 169. APPARATUS FOR EXAMINING THE EFFECTS OF VARIOUS CONDITIONING FACTORS ON TRANSPIRATION.

7. Look for the exuded drops of water on the blunt edges of a *Tropœolum* leaf in the early morning. If possible, examine and draw the microscopic structure of the hydathodes of this plant and also of *Phaseolus*. Since these are difficult to obtain by the ordinary methods of section cutting by hand, it is recommended that prepared slides be obtained.

8. Cut transverse sections of the leaves of the cross-leaved heath and marram grass. Examine these sections under the microscope, noting especially the shape of the leaves, and the presence of hairs on the inner surface. Look for stomates and make orientation sketches of the sections, indicating the position of the stomates. Fully describe and discuss the difference between these leaves and a normal leaf.

9. Examine prepared slides of the transverse sections of the leaves of the Scots pine and *Hakea*. Examine under the high power and draw in detail the structure of a stomate and its surrounding tissues. Note the sunken nature of the stomate and (especially in the case of *Hakea*) the especially thick cuticle. Explain these abnormalities.

10. Show that the path of the transpiration current is through the vascular bundles.

Dilute some red ink, and stand some white flowers, such as narcissus, in it. After a time, notice that the white petals turn pink, but only in their veins.

11. Show that the transpiration current passes through the wood of the vascular tissue. Perform the same experiment again, using an elder twig. After a few hours, cut the stem some distance up, and examine the cut surface with a lens. Note that only the wood has become pink.

12. Perform Hales's ringing experiment, using a twig of willow. Fully discuss the significance of the results obtained.

13. Carry out the same experiment, but leave the twigs standing in water for some days. Then look for the production of adventitious roots, and note their position in relation to the ring. Fully explain this.

14. Examine and draw several types of cactus plants. These are often grown in greenhouses, and can usually be seen in botanic gardens. Discuss their modified structures, especially with relation to their normal desert habitat, and its effect on transpiration and water-storage.

CHAPTER XIII

RESPIRATION AND FERMENTATION

ALL living things must perform a certain amount of work in order to live, for all processes of the living body involve work. For example, animals must work in order to move, so also must plants. Work is involved in breathing, digestion, thinking, reproduction, etc. This therefore demands the use of some sort of energy, since work involves the utilisation of **energy**. Energy is the capacity to perform some process of work.

Potential Energy in the Plant

Now energy exists in several definite forms. Energy due to motion is said to be **kinetic**; for example, water wheels are turned by the kinetic energy of rivers. Energy due to position or storage is called **potential** energy, such, for example, as water at the top of a cliff, or the wound-up spring or weights of a clock.

The potential energy of a wound-up spring is liberated as kinetic energy, when the spring is released. Thus, energy can exist in different forms (the two here being potential and kinetic) which can be transformed the one into the other. A charged Leyden jar possesses energy in the potential state, yet when it becomes discharged, the energy is released as **electrical** energy. This electrical energy can again be transformed into another form of energy, that of **heat**. For example, electrical energy passing along a wire, if allowed to pass through a resistance, will be transformed into heat energy. This forms the basis of the electric fire. Thus there are several forms of energy, potential, kinetic, chemical, electrical, heat, and so forth. Not

only do these forms of energy exist, but also it is possible, in certain circumstances, to transform one form into another.

Radiant Energy

The main consideration for the moment, however, is the energy which is involved in the various living processes of animals and plants. All such processes require energy. It does not matter so much, at first, in what form, for the primary question is: What is the source of the energy? Whence do plants and animals derive their energy, which they require for their life processes?

Recapitulation of what has already been learned of photosynthesis will soon show the source of this energy, and will also help to explain the reason for the important process of photosynthesis. The *immediate* source of energy for plants and animals is the food which they manufacture and consume. In other words, food-stuffs of all kinds contain potential energy. But, if this is the case, what is the *ultimate* source of this energy? In other words, whence do the food-stuffs obtain their potential energy, since, within certain limits, energy cannot be manufactured afresh?

This takes us back still further in our former considerations of food manufacture. It has already been seen that one of the most important conditions necessary for photosynthesis to take place is the presence of light. Of course, this can be assured by supplying artificial light, such as gas or electric light; but, in Nature, the light is always supplied by the sun. This is why light is such an essential factor in photosynthesis, for the process of photosynthesis takes place *in order to make use of the light.*

Light is fundamentally another form of energy. The energy given off by the sun is therefore called **radiant energy**. It is this radiant energy which is really the *reason* for photosynthesis. During the building up of carbohydrates, etc., by the process of photosynthesis, some of the radiant energy of the sun is absorbed and stored in the food in the form of potential energy. The process of photosynthesis can therefore be represented in the

following manner, at the same time demonstrating the fundamental reason for the process:

carbon dioxide + water + (radiant energy) →
from the sun.
carbohydrate + (potential energy) + oxygen
for the plant's life processes.

This gives part of the answer to the question: why is photosynthesis so necessary to all living things besides green plants? It is clear now that the only ultimate source of energy for all living things is the radiant energy of the sun; and this can only be trapped by the process of photosynthesis, which, in turn, can only take place in green (that is, chlorophyll-containing) plants.

So now we have the living things with the energy so necessary to them available. *It is present in the potential form in their food-stuffs.* But, as such, it is useless. Energy only becomes useful when it leaves its potential state and becomes transformed into a more 'dynamic' form.

Release of Energy in Living Things

Since energy is stored up in foods while the foods are being built up from the raw materials, it is clear that such energy would be released if the foods could be broken down again into their raw materials. In other words, if the manufacture of food involves the trapping of energy, then the breaking down of foods should involve the releasing of energy. This is exactly what happens. Plants and animals absorb energy-containing foods, merely in order to break up those foods and extract the potential energy in them.

This process of energy-extracting from foods is called **respiration**. In certain superficial respects, as one would imagine, the process of respiration is the opposite of photosynthesis, which process involves building up carbon dioxide, water and radiant energy into food-stuffs, oxygen, and potential energy. Respiration involves the absorption of oxygen and breaking down the food-stuffs and potential energy into carbon dioxide, water

and, not radiant energy, but other forms of energy that the living organism requires.

Since oxygen is given off during the process of photosynthesis, as would be expected, this gas is used up in the process of respiration. Thus the process of respiration can be represented in the following manner :

$$\text{carbohydrate } (+\text{potential energy}) + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{working energy.}$$

This explains why oxygen is necessary to all forms of life, since respiration is essentially an oxidative process. The oxygen used is that present in the atmosphere. Living things use this oxygen during respiration and give off carbon dioxide, a suffocating gas, during the same process. That is why the atmosphere in which an animal has been allowed to breathe for some time is unhealthy, since it is depleted of its oxygen, which is necessary for the process, and at the same time suffocated by the carbon dioxide given off during the same process. For this reason it is necessary to keep all rooms well ventilated, to allow the contaminating carbon dioxide to escape and the necessary oxygen to enter.

During the process of respiration in man, and many other animals, the carbon dioxide is given off into the blood vessels, carried through them in chemical combination with the blood hæmoglobin to the lungs, and there exhaled into the atmosphere. This can be proved in a simple manner. Carbon dioxide will turn lime water milky. If we therefore blow down a glass tube into a solution of lime water, the lime water will gradually become milky owing to the carbon dioxide being exhaled through the process of respiration.

A green plant, on the other hand, can be kept in an enclosed space much longer than an animal can. This is because the process of photosynthesis is taking place, which, up to a point, counteracts the effect of respiration ; for, whereas respiration involves the giving off of poisonous carbon dioxide, photosynthesis involves its absorption, and though respiration means the absorption of the necessary oxygen, photosynthesis gives it out again. Clearly this is only the case in the presence of light.

Now, living things naturally continue to live during the hours of darkness. Therefore, they are working more or less, all the time, night and day ; consequently they respire during the night. In other words, *respiration never ceases while the organism is living.*

In the green plant, therefore, although, during the day, photosynthesis and respiration are taking place together, only respiration is going on during the night. Thus, up to a point, plants, like animals, contaminate the atmosphere by their respiration during the night, whereas, during the day, by virtue of their photosynthetic properties, they help to purify the air. This is the reason why plants and cut flowers are allowed to stay in a sick-room and in the wards of nursing homes and hospitals during the day, but are removed at night. Actually, however, the trouble to which the nurses go in removing plants from the wards when night falls is scarcely necessary. It is true that the plants do contaminate the atmosphere, during the night ; but the amount of contamination involved is very small indeed. Not only is it very small, but the ventilation, even in a poorly ventilated room, would succeed in driving out all contaminating carbon dioxide given off by the plants, and also in more than replenishing the amount of oxygen absorbed. So, although it is true that plants tend to contaminate the air in a room during the night, the amount of contamination is so negligible and the circulation of pure air so much greater, that to remove plants in the evening for this reason is really unnecessary.

Rate of Respiration

Respiration takes place at very varying rates in different plants and different animals ; also in the same plant, or the same animal, at different times. It all depends, naturally, on the amount of work being done. If the plant or animal is working at high pressure, then respiration takes place at a great rate. If, on the other hand, very little work is being performed, then the rate of respiration is very slow. For example, if a man continues to dig in his garden for a long period he is doing a great deal of work. Again, anyone taking part in a race is working at high pressure when running. The result is, respiration goes on at a

great rate. Therefore, more oxygen than usual is required, with the result that breathing becomes deeper and quicker until the man digging or the person running sometimes even has to puff and blow in order to get sufficient oxygen. Then, if such a person sits down to rest, much less work is being done, though a certain amount, such as the work involved in the beating of the heart, the digestion of food, etc., is still going on. This results in a slower respiration and consequently a more easy and slower breathing. When asleep, the amount of work is still further reduced, and thus breathing becomes even more steady.

As respiration increases, obviously more food is required. Therefore, a very active person requires to eat more food than a very passive one. That does not necessarily mean that a hard-working manual labourer, such as a farm worker or a quarryman, an athlete, or a blacksmith, necessarily requires more food than a more quiescent person such as a school teacher, stockbroker, or clerk. For, whereas one does much manual work with his muscles, the other may do just as much energy-using work with his brain. What it actually means is that the worker (in some form or another) requires more food than the non-worker; because the former must have energy in order to work, and this is obtained by the respiration of the foods. It has been shown that a football player may lose as much as seven or ten pounds in weight during a game. Much of this loss is due to the using up of foods during his excess respiration. A man in good condition, however, usually regains his weight during the same day.

Variations of rates of respiration are just as common in plants as they are in animals. For example, a deciduous tree is obviously carrying on more processes involving work during the summer (since it is growing and developing) than it is during the winter. Therefore, respiration goes on at a greater rate during the summer period. Also, seeds when they are in storage are undergoing very little activity. Thus, little energy is required and therefore little respiration. That is why they can easily be stored in jars or packets, where only a little oxygen at a time can penetrate. When they are sown in the soil, however, they germinate and grow. This period of growth involves a great deal

of work and expenditure of energy. Then, respiration takes place at a very great rate.

It is now clear why all the living parts of the plant, even the roots, must have some available air, since it is the air which supplies the oxygen. During respiration, oxygen is taken in and carbon dioxide given off. Thus there is a gaseous interchange taking place between the living cells and the atmosphere. This gaseous interchange takes place all over the surface of the plant, where possible. It is not very easy through cuticle or bark, as has already been seen, therefore it takes place to a considerable extent through the stomates of the leaves, and also through the lenticels on a secondarily thickened stem. In fact, the gaseous interchange involved in respiration is the main reason for lenticels. In the case of roots, respiration takes place through the surface of the piliferous layer.

Forms of Plant Energy

The energy extracted from the foods during respiration assumes several forms. Much of it is **chemical** energy to allow the various chemical processes involved in the living cells to take place.

Some of the energy liberated by respiration, however, is almost invariably **heat** energy. Thus, respiration causes a rise in temperature within the plant or animal body.

This giving off of heat during respiration explains many familiar phenomena. For example, we ourselves are warm-blooded animals. In normal health, our temperature is just a little more than 98° F. This temperature has to be kept up, never mind what the temperature of the surrounding atmosphere may be. It is done by respiration, which liberates energy in the form of heat. Even a person doing scarcely any work, such as an invalid, must have food, for this reason alone.

Now since heat is nearly always given off during respiration, the more food one consumes, the higher the temperature becomes, because one respires more. A runner, for example, is working hard, and therefore respiring quickly. The result is, a greater liberation of heat. That is why he becomes very hot, even on a very cold day.

The same thing can be seen in the case of plants. Box peas, for example, which the cook uses for culinary purposes when fresh ones are not available, are living seeds. But they are very much at rest since they are very dry, and their respiration is consequently very low. But, before using them, the cook usually soaks them overnight. By osmosis, the peas absorb water, and in doing so, their vitality is raised and they respire at a greater rate. Therefore a certain amount of heat is liberated. This explains why, if you put your hand into the peas after soaking them for nearly a day, they will feel perceptibly warm.

A similar case may be seen when cutting the grass on the lawn. As the grass is cut, it is usually collected and piled into a heap. Now all those cut blades of grass are living. They are therefore respiring, and consequently give off a certain amount of heat. For this reason, the inside of the grass heap will be found to be quite hot after a day or two.

This fact also explains why hay ricks sometimes catch fire. The farmer knows that such a catastrophe is not so much due to a possibly scorching sun, as it is to putting up the hay when it is still wet. If the hay is perfectly dry, all the grass is dead and cannot respire. On the other hand, if it is wet, much of it is probably still alive, and can respire and give off heat. This may go on to such an extent that the compact mass of hay will not allow the liberated heat to escape, with the result that a fire finally takes place.

An exceptional but very interesting example of excess respiration resulting in the production of heat is seen in the alpine plant, *Soldanella alpina*, common in the Swiss Alps. This plant develops thick, leathery leaves in autumn. These contain plenty of reserve starch, and are thus well equipped with combustible fuel. During the winter, the plant becomes completely covered by snow and ice to a depth of several feet. Then, when spring comes, the sun melts all the snow and some of the ice, water trickles down to the plant roots, and respiration then becomes more active. Much food is passed to the flower-buds, and in their excessive respiration they give off sufficient heat to melt the ice around them. Thus, the developing flower actually melts its own way through the ice. When the flower is fully developed,

whole blue patches of them may be seen, as if they are growing on, and in, ice. By the time the flowers have pushed their heads out of the ice, the leaves have become thin and papery, since so much of their stored food has been used up in this great respiratory activity.

During the process of respiration, oxygen is taken in. This is because, during the chemical reactions involved in the breaking down of the food-stuffs, oxidation takes place. In other words, respiration involves the oxidation and splitting up of the food-stuffs within the body. It is therefore an oxidative process ; the process taking place within the protoplasm of the living cells.

The chemical changes thus involved are still further examples of enzyme activity, for the oxidation would be far too slow without the help of such enzymes. Since these enzymes help in oxidising the food they are collectively called **oxidases,** though there are several different ones, each of which has its own specific name.

Combustion of Plant Materials

Respiration is very similar to combustion. The latter process involves the chemical absorption of oxygen with the giving off of carbon dioxide, together with the splitting up of some complicated chemical compound. At the same time, energy is released in the form of heat. Respiration, therefore, may be looked upon as a slow form of combustion.

The heat of combustion of an element is measured by causing it to combine with oxygen in an enclosed chamber and measuring the heat evolved calorimetrically. For example :

$$C + O_2 \rightarrow CO_2 + 94{\cdot}8\ K.$$
$$H_2 + O \rightarrow H_2P + 69\ K.$$

Thus, 12 grams of carbon yield 94·8 kg. calories (K) on complete oxidation and 2 grams of hydrogen, 69 kg. calories. Since the heat (measured in calories) is a form of energy, the **calorific value** of any substance, measured in the above way, may be considered as a direct **respiratory** value ; and it is clear that since oxygen cannot have any calorific value, then the more oxygen a food contains, the less is its respiratory value. From this it may

be deduced that the *average* respiratory values of the common food-stuffs are: carbohydrate : protein : fat = 2 : 3 : 4·4. Therefore protein foods have a higher respiratory value than carbohydrates; and fats still more. That is why fatty foods are more 'heating' than farinaceous foods. The Eskimo living in intensely cold regions lives chiefly on fatty foods. The relative respiratory values of common foods, considered from this point of view, are illustrated in Fig. 170.

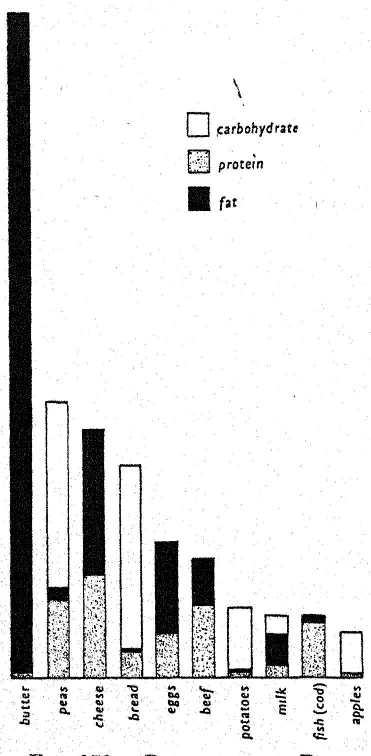


FIG. 170. DIAGRAMMATIC REPRESENTATION OF THE COMPARATIVE RESPIRATORY VALUES OF COMMON FOODS.

(*After Hutchinson and Mottram.*)

Many of the built-up substances in the plant body, though they are not food-stuffs, naturally contain some potential energy since they have been primarily manufactured by photosynthesis. Yet they are not usually made use of in respiration. For example, the wood vessels, the cellulose cell-walls, etc., form the plant skeleton and do not enter into the process of respiration at all; yet they are indirect products of photosynthesis. Their potential energy is therefore stored throughout the life of the plant.

Yet in certain everyday activities of man, the presence of such potential energy is made clear. For example, timber is a combustible body. Given certain well-known conditions, it will burn, and in doing so absorb oxygen and give off carbon dioxide, among other gases,

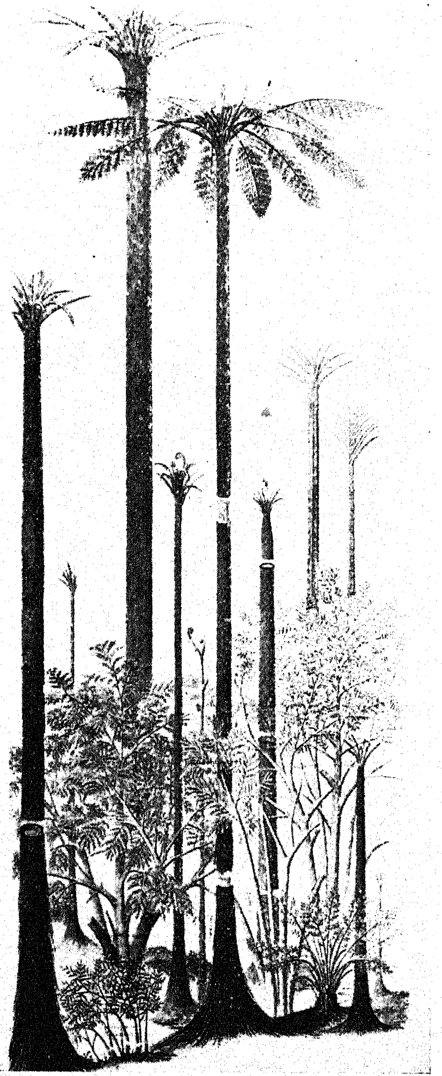


FIG. 171. RESTORATION OF FERNS, ETC., GROWING IN THE CARBONIFEROUS (COAL) AGE.

(Scott, "Extinct Plants and Problems of Evolution." After Grand' Eury.)

together with the freed energy in the form of heat. So also will cotton, straw, etc.

Coal and Petroleum

A still better example is **coal**. This is a well-known combustible body which gives off carbon dioxide and other familiar gases, together with heat energy, at the same time absorbing oxygen during its combustion.

It is known that the earth's crust is many millions of years old. During all that time the crust has gone through many changes, and the time, so far as we can trace it back, is subdivided into definite geological periods. One of these is called the **Carboniferous** period or, more popularly, the **Coal Age**. This period or age existed millions of years ago. At that time, no flowering plants were living on the earth. Such plants have developed since. During the Carboniferous period, the dominant plants on the face of the earth were very similar to our present-day tree-ferns, horsetails and club-mosses. But they were not exactly the same ; for example, the common horsetail of to-day is a small herb, never growing much more than about two feet in height. The similar plants of the Carboniferous age, on the other hand, were huge trees (Fig. 171). Gradually this age began to disappear, and give place to a later age.

Remnants of the Carboniferous period, however, still remain with us, since they have become buried hundreds of feet underneath the earth's surface. In this way, plants of that age have become preserved, though very compressed. A great deal of the Carboniferous remnants of to-day is of economic importance in supplying coal. It is necessary, in order to get the coal, to mine it, and this often involves going several hundreds of feet down into the earth's crust.

As the Carboniferous strata became buried, by various methods, its plants and animals became buried too. After burial, the plants and animals were subjected, for thousands of years, to tremendous pressure from the layers above. This caused great compression, which involved the production of much heat. In this way the coal as we know it was formed. Coal is therefore chiefly the carbohydrate matter of countless plants, chemically

modified and compressed (carbonised). This can be proved by examining coal hewn from a mine. It is often possible from such

FIG. 172. *Williamsonia*, FROM MEXICO, SHOWING FLOWERS, FOLIAGE, AND BRANCHED STEM AS EXPOSED ON A SLAB OF LIASSIC ROCK.

(Scott, "Extinct Plants and Problems of Evolution": from a photograph supplied by Dr. Wieland.)

coal to pick out pieces which bear unquestionable impressions of fern-like plants on them. Such impressions are referred to as fossil plants (Fig. 172), just as it is possible to find fossil animals.

Now, since coal is formed from the bodies of plants, there must be a great deal of potential energy in it as a result of the photosynthetic activity of those plants, when they were living on the earth. This we know is the case, for when coal is burned, or undergoes combustion, energy is given off in the form of heat.

Here is a splendid example, therefore, of the great energy-supplying activities of plants, through their storing up potential energy during photosynthesis. This is not all. The great value of plants is demonstrated in these fossilised plants, or coal, by not only the great energy they supply through burning, but also by valuable by-products such as coal-gas, oils, aniline dyes, salts, coke, etc. These products are usually obtained during the manufacture of coal-gas.

Another possible manner in which the stored energy of plants millions of years old may be revealed is through petroleum. This substance is of very great value to-day in all manner of forms. It is found in various strata in the earth's crust, especially in the United States, Russia, Persia and Iraq. There is one theory that petroleum is derived from the decomposition of plants buried many thousands of years ago. However, this question has never been settled, and there are other theories. Therefore, we can only leave the supply of energy by plants from ages past, through the medium of petroleum, as a possibility.

Respiration without Oxygen

It is quite clear that in order to respire, normal plants must have oxygen. This is usually supplied by the atmosphere, since about one-fifth of the air is composed of oxygen.

But plants can withstand the absence of air up to a point. If this is so, then it is true to say that, *for a time*, plants can respire in the absence of air. If, therefore, a plant be put into an atmosphere absolutely devoid of oxygen, it will continue to respire for a short time, but *only* for a short time; after it the plant dies.

Now, ordinary respiration in the presence of air results in the complete splitting up of carbohydrates into carbon dioxide and water, with the absorption of oxygen. In the absence of oxygen, therefore, it is naturally to be expected that the chemical pro-

cesses involved will be different, since there is no oxygen present to react. This is actually the case. While respiration continues in the absence of oxygen, the foods are never *completely* broken down into the raw materials. The process only goes part of the way, with the production of about a third of the possible carbon

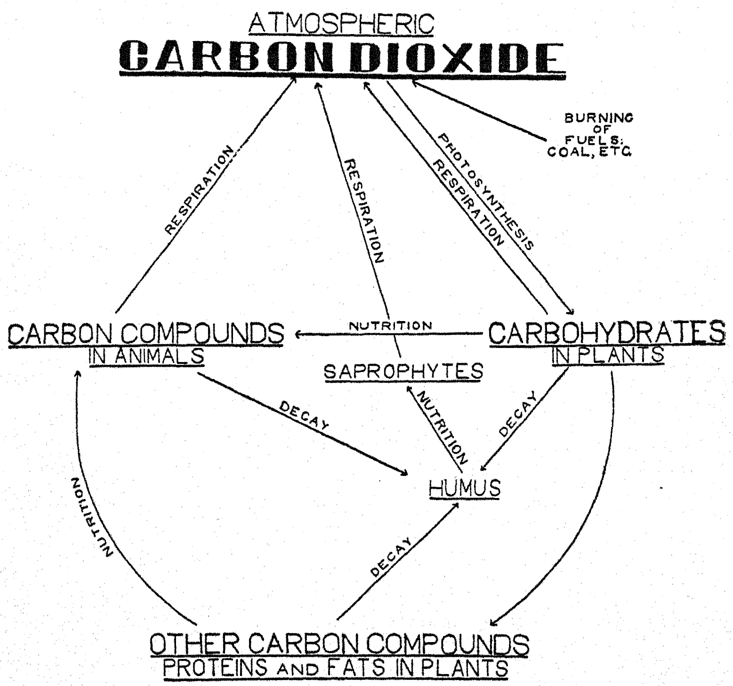


FIG. 173. THE CARBON CYCLE.

dioxide and no water at all, but **ethyl alcohol**. The last-named substance is capable of being broken down still further if oxygen were present, with the release of even more energy. Therefore, this type of respiration is a wasteful process.

Normal respiration, that is, respiration in the presence of oxygen, is referred to as **ærobic** respiration. Respiration in the absence of oxygen is called **anærobic** respiration. The former

involves the complete splitting up of foods with the liberation of all the energy. The latter, on the other hand, involves only partial splitting of the foods, with a consequent release of only part of the potential energy.

Normal plants can respire anærobically only for a very short time. But there are a few plants which *normally* respire anærobically. In fact, in some cases, such plants die if they are exposed to oxygen. Such plants are therefore called **anærobes.** There are only a few of them, comparatively speaking. Nearly all are bacteria. For example, the bacterium which causes tetanus or lock-jaw lives in the soil, and is an anærobe. Therefore, if there is any suspicion that this bacterium has penetrated a flesh wound, the best thing to do is to cleanse the wound with an antiseptic which has oxidising properties, such as hydrogen peroxide.

A comparison of the processes of photosynthesis and anærobic respiration in the following table, and also in Fig. 173, will show the relationship between the element carbon and living things (often referred to as the **carbon cycle**).

	Photosynthesis.	Respiration.
1.	Takes place only in chlorophyll-containing cells.	Takes place in all living cells.
2.	Raw materials are carbon dioxide and water.	Raw materials are food-stuffs and oxygen.
3.	Takes place only in the presence of light.	Takes place at all times, day and night.
4.	An energy-absorbing process.	An energy-releasing process.
5.	Products are food-stuffs (especially carbohydrates) and oxygen.	Products are carbon dioxide and water.

Alcoholic Fermentation

Glucose, if allowed to remain exposed to the air in solution, will undergo a chemical reaction, in which it forms ethyl alcohol and carbon dioxide. The process is accelerated by the addition of yeast, and it is known as **alcoholic fermentation.**

In certain respects, alcoholic fermentation and anærobic respiration are similar, especially in that a carbohydrate is used and the end-products are ethyl alcohol and carbon dioxide. But both processes are very complicated ones, and although we

know that alcohol and carbon dioxide are the chief end-products of the reaction, there are several intermediate stages. That is, several substances are produced before the end-products appear. The complete sequence of chemical events is still not clearly understood.

Yeasts

Alcoholic fermentation is of very great importance to-day. From the commercial point of view, it is quite clear that merely to leave the plant decoctions to ferment of their own accord would scarcely be a profitable business. The process would be far too slow. This problem has been settled by the use of an enzyme called **zymase**. This enzyme has the property of speeding up the process of alcoholic fermentation.

Zymase is produced by a family of small unicellular plants belonging to the fungi, which are called collectively **yeasts**. There are several kinds of yeasts, and they are present on the earth in their millions. Certain yeasts are better for certain types of fermentation.

The yeast plant used in beer-making is called *Saccharomyces cerevisiæ*. This is a unicellular plant, and is visible only under the microscope. Each cell is oval in shape and may exist separately or loosely joined together in long chains (Fig. 174). It is composed of a mass of cytoplasm containing a nucleus.

The curious thing about the yeast cell is that, although it contains one large vacuole, this vacuole is not present in the cytoplasm, as in the case of the normal plant cell, but is present inside the nucleus itself. The vacuole is therefore said to be **intranuclear**.

The whole cell is surrounded by a thin cell-wall. It contains no chlorophyll whatever. Therefore, in this respect the yeast plant differs from the normal plant in that it cannot manufacture its own food. It therefore lives on sugary substances, such as the fermenting plant-products offer, in order to obtain its food. The protoplasm of the cell has the property of manufacturing comparatively large quantities of the enzyme, zymase.

When the cell has reached a certain size it develops an outgrowth, and as this outgrowth gets larger, the nucleus divides

into two portions, and one of the portions passes into the outgrowth, which gradually becomes constricted off from the parent cell and forms a new plant cell. This is another method of vegetative reproduction. The outgrowth is usually referred to as a bud, and the process is therefore called **budding** (Fig. 174). This

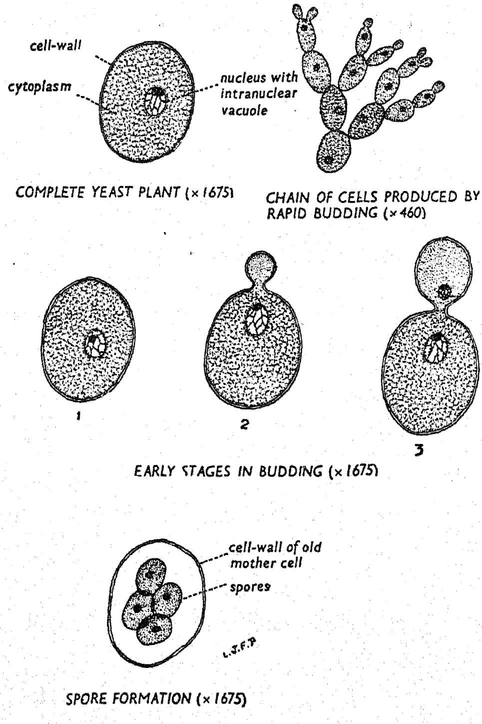


FIG. 174. THE YEAST PLANT.

process of budding, given favourable conditions, goes on at a very great rate. That is why, if a little yeast be placed on the top of a solution of glucose (thus supplying the yeast with good nutrient material) and then kept in a warm place, it very quickly begins to form a frothy substance at the top. This froth is a mixture of (*a*) the millions of yeast plants being formed by budding; (*b*) some of the sugar solution; (*c*) millions of

bubbles, chiefly containing the carbon dioxide being formed during the fermentation of the glucose.

There is another method of reproduction in the yeast plant, which usually takes place when the cell is not subject to healthy conditions. In this case the cell contents divide themselves up into about four portions. Each portion surrounds itself with a thick wall, and then, when the wall of the original cell disintegrates, all the portions escape (Fig. 174). Each portion is called a **spore**, and each spore is capable of developing into a new yeast plant.

Now, since the spore is surrounded by a thick wall, it can withstand adverse conditions such as frost, or desiccation. There are millions of these spores formed by yeast plants all the time. They are very light, since they are so small. The result is that they are blown about in the air.

The atmosphere contains millions of spores, not only of the yeast plant, but also of others. That is why yeast very often appears on a sugary substance, after the latter has become exposed to the air for some time. Some of the spores from the atmosphere settle on it, and, on finding good nutrition in the sugar, they develop into adult yeast plants. For that reason, in the brewing industry, since the special yeast, *Saccharomyces cerevisiæ*, is the one required for the fermentation, great care has to be taken that the spores of other yeast strains do not get on to the fermenting material, from the atmosphere. If they do, they spoil the flavour of the beer.

The apparently sudden appearance of bacteria and fungi, in the form of disease, etc., is explained by the presence of these many spores in the atmosphere, in water, etc. It is practically impossible to say exactly how many different forms of fungi alone there are in the world ; 100,000 is a rough, though possibly a conservative, estimate. The spores of most of them exist almost everywhere, since they can withstand adverse conditions that the normal living plant and animal cannot (see also pp. 292, 310 and 311).

For this reason, given suitable conditions of growth, they soon develop in the most surprising places. Apart from suddenly attacking animals and other plants and thus often causing dis-

ease, some make their appearance on the soil, and in the household on stale, uncovered foods, on preserves such as jams, on damp clothing, leather, wall-paper and plaster. Special precautions are therefore necessary to prevent the development of such spores. During the preservation of food, for example, the material is usually sterilised, thus killing any spores present, by the application of heat. In the case of jams, sterilisation is effected not only by the heat applied, but also by the presence of much sugar. *Excess* sugar is unfavourable to the development of fungal spores. When the jam is exposed to a damp atmosphere, however, water is absorbed by the sugar present, and the concentration reduced enough to allow the development of moulds.

Wooden structures, etc., are protected from attack by treatment with creosote, tar, etc.

Baking of Bread

The giving off of carbon dioxide in such great quantities during alcoholic fermentation is utilised in the baking of bread. Bread is composed chiefly of flour, which contains a considerable amount of starch. Now, since starch is split up into sugar by the action of diastase, it is to be expected that a certain amount of sugar will always be present, wherever there is starch. Therefore, there is always a certain amount of glucose in flour.

In bread-making, a little yeast is added to the flour when it has been kneaded into dough. This, by supplying the enzyme zymase, causes the alcoholic fermentation of the glucose present in the flour. As a result, alcohol is produced, but not enough to cause any material damage to the bread. On the other hand, carbon dioxide is given off in considerable quantities. This gas passes throughout the flour, forcing the particles of flour apart, thus causing it to 'rise,' and making it lighter.

Within limits, a rise in temperature causes an increase in all enzyme activity. Therefore, when the dough is placed in the oven, as the temperature of the dough rises, so is the process of fermentation stimulated to greater activity. But, after a few minutes, the activity ceases altogether, since at very high temperatures the yeast plants, and also the enzymes, are killed.

For this reason, in order to get a good 'rise' in the dough, it is not immediately placed in the oven, but put in front of the fire, or in a very 'slow' oven, where the heat is sufficient to cause rapid activity of the yeast, but not sufficient to kill it. After a time the baking is finished off in a hot oven.

Baker's yeast is usually supplied by the brewer. It is not often supplied as the foamy material scooped off the top of the fermenting liquor, but usually in a dry, powdery form called **barm** or **leaven**.

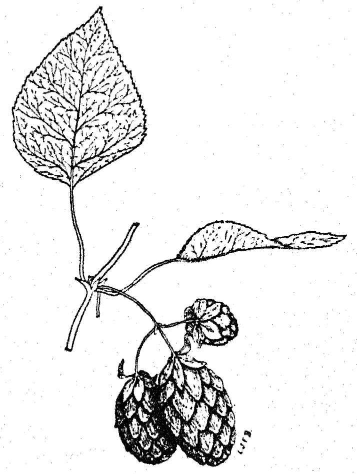


FIG. 175. FRUIT OF THE HOP.

Brewing

Beer is one of the commonest of alcoholic beverages. It is also one of the oldest. There is evidence that prehistoric man was able to make it. In ancient Babylon it was certainly known, that is, so far back as 5000-6000 B.C. It was a common drink in ancient Egypt; and in both Babylon and Egypt it was used in medicines as well as in beverages. The Greeks also were very fond of it. During medieval times, both in Great Britain and on the Continent, the value of yeast in both brewing and baking was known, and to this day, in the monasteries, the brewery and the bakery are often found side by side. To-day beer-making is known all over the world, even amongst savage tribes; though not so much amongst the arctic peoples, chiefly owing, perhaps, to their inability to get the raw materials.

The fundamental plant in the brewing industry is the **barley** (*Hordeum vulgare*). This plant probably originated in western Asia, but it is now cultivated in many parts of the world—all over the continent of Europe, Great Britain, etc. In brewing, the grain of the barley is used. The grain must be of a very fine quality, and well developed.

The grains are soaked and then allowed to germinate. Now, the barley grain contains much starch as a food reserve. As the grain sprouts during germination, it goes through a great deal of respiratory activity. Therefore, the starch is broken down, by the diastase which is present in the grain, into glucose. This is what is required for the fermentation. The action of the diastase is allowed to go on for about a fortnight at a temperature of about 100° F. Then the heat is increased, and the amount of moisture decreased so that the barley seedlings die. The result-

FIG. 176. A HOP GARDEN IN KENT.
(*By courtesy of "The Times."*)

ing dead barley seedlings form what is called **malt**. Scrupulous care has to be taken in making the malt, in order to prevent any kind of contamination. Heat to kill the barley seedlings is produced either under the floor of the malt-house or by passing hot air through it.

The malt, after drying, is ground and then placed in water, thus producing what is called **wort**. The wort is boiled to kill the action of the diastase and any contaminating bacteria that may be present.

To this wort, **hops**, the fruit of the hop (*Humulus Lupulus*) (Fig. 175), are now added for flavouring purposes. This was not always the case, however, for hundreds of years ago the flavour-

ing was produced by adding certain spices. The mixture of wort and hops is then boiled and allowed to stand for some days. Then the hops are removed, the wort is cooled to about 60° F., and the special yeast, *Saccharomyces cerevisiæ*, added and fermentation takes place. This is allowed to proceed for some weeks. Then the yeast is removed, and the resulting beer stored in vats, to mature.

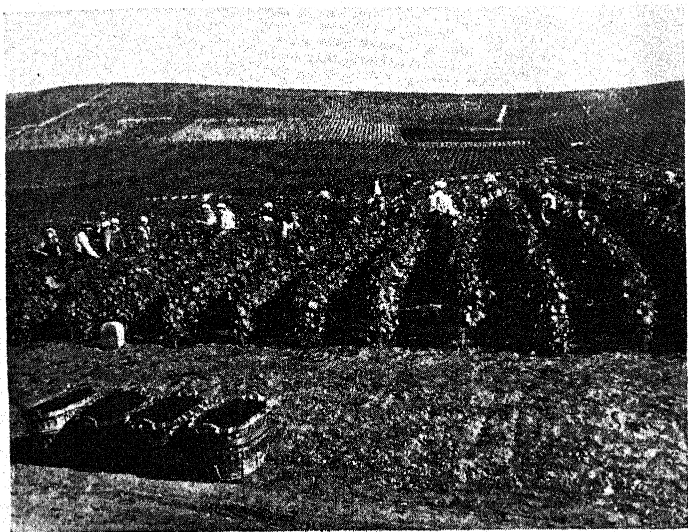


FIG. 177. GATHERING GRAPES IN A FRENCH VINEYARD.
(*Photo. Charles R. Brown.*)

Barley for brewing purposes is grown in various parts of Great Britain, especially in Scotland. The hops are grown to a great extent in Kent (Fig. 176), the total acreage of hop gardens in Great Britain being about 16,000.

Brewing is an important industry in Great Britain and on the Continent. Certain places are very famous for the industry, chiefly because the water of the district gives a specially good flavour to the resulting beer. This is the case in Burton-on-Trent, in Staffordshire, where brewing has become the leading industry. In fact, the water there is claimed to give such an

extraordinarily good flavour to the beer that the water itself is sent by road and train to breweries in other towns, miles away, such as Manchester.

North Continental beers are usually lighter in colour and, indeed, in effect than British beers. These lighter beers are called **lager.** The difference lies chiefly in the different types of yeast used. In Great Britain, what is called **top yeast** is used. This is because, as fermentation proceeds, the yeast rises to the top. On the Continent, **bottom yeast,** which remains at the bottom of the fermenting liquor, is used. Lager, which is usually a bottled beer, and, indeed, any other bottled beer, gives off bubbles of gas when opened. This is because the beer is bottled before fermentation is complete. The process of fermentation, therefore, goes on within the bottle, and the carbon dioxide produced remains in solution, under pressure. When the bottle is opened, the pressure is suddenly released, and the carbon dioxide comes out of solution as the familiar bubbles of gas.

Closely connected with beer-making is the manufacture of spirits. This in its turn is related to **wine-making.** The two differ in that such spirits as **whisky** are made from barley and other cereals, whereas wine is made from the fruit of the grape.

Wine is more peculiar to southern peoples, such as those of the Mediterranean countries, whereas whisky is made to a great extent in the more northerly countries, such as Great Britain, especially Scotland, and Ireland.

The cereals used for preparing the wort for whisky are chiefly barley, oats, wheat and rye in Ireland, whereas in Scotland it is usually only barley. After a certain time, this wort is distilled, thus producing the whisky. The various flavours depend chiefly on the water used, which comes from peaty soils. Whereas the chief alcohol in beer is ethyl alcohol, in whisky the chief alcohol is **amyl alcohol,** and the others present are butyl, propyl, and a small amount of ethyl.

Rum is distilled from fermented cane-sugar or from molasses. **Gin** is formed by the redistillation of the crude spirit with the fruit of the juniper (*Juniperus communis*). **Brandy** is distilled from fermented grape juice.

Wine-making

Wine-making is an important industry in Mediterranean countries, especially France, Italy, Spain and Portugal, and also in Germany. The chief wine-producing country in the world is France, which possesses nearly 4,000,000 acres of vineyards. There, wine is a common beverage, being consumed more or less as tea and coffee are consumed in Great Britain. Italy is the second largest wine-producing country, with more than 2,500,000 acres of vineyards. Australia and South Africa are now quickly developing their wine industries.

Wine is the fermented product of freshly gathered grapes. For this reason, the vineyards of France, etc., are famous all over the world (Fig. 177). Wine is produced by crushing the grapes and then allowing fermentation to take place. Here, there is one important difference from that of beer-making, because in wine-making the yeast need not be added. Yeast spores are very common in the atmosphere, as already stated, with the result that yeast plants grow on the skin of the grape. This naturally occurring yeast supplies the necessary enzyme, zymase.

Red wines are more or less the pure product of fermentation of the grape juice. In the case of **port** wines, extra alcohol is usually added. **White** wines are treated in various ways to get rid of the colour. **Sparkling** wines differ from **still** wines in that they are bottled before fermentation is complete, as in the case of bottled beers, with the result that the carbon dioxide, formed after bottling, is released on opening the bottle, thus giving the sparkling effect. In wine-making the whole fruit of the grape, including the skin, is used. On the other hand, **champagne** is prepared from the juice only. No skin is used. That is one reason why this beverage is so expensive.

Vinegar

A by-product of wine-making is **vinegar**. This substance is also manufactured during the making of **cider**, which is a beverage produced from the fermentation of the juice of the apple. There is little doubt that vinegar was first produced, probably by the ancient Greeks and Romans, by the natural souring of cheap

wines; but it began as a separate industry for the first time in the seventeenth century in France. The reactions which take place in such a process involve chiefly the production of acetic acid from the alcohols in the wine. Acetic acid is the main constituent of vinegar. The organism responsible for this souring is a bacterium known as *Bacterium aceti*.

Power Alcohol

Alcohol may have a great future, not as a beverage but as a means of producing power, in place of the widely used petrol of to-day. Already there is an Act in force in Czechoslovakia which compels the use of 23 per cent. ethyl alcohol to 77 per cent. petrol in all motor engines. This is calculated to help the great potato industry, for it is the starch of the tubers which is used as the fermenting material. In Germany also gasoline must contain at least 10 per cent. alcohol, else a tax is levied.

In view of the absence of oil-wells in Great Britain, the establishment of alcohol as a means of power would prove a boon to this country, although the production of petrol from coal is already being established on a commercial scale.

To-day, industrial alcohol is produced chiefly from molasses, and a purity of 99·99 per cent. can be obtained cheaply. Until 1932, the purest commercial alcohol was only 96 per cent. absolute. It is this attainment of a much purer product which has made the advent of power alcohol a certainty, because the main impurity formerly was water, and if water is present, alcohol will not mix with petrol.

Many practical tests in several countries have confirmed the utility of alcohol as a motor fuel. Indeed, it is common practice to use a proportion of it in racing cars. In Paris, most of the omnibuses use it in a 50 : 50 mixture of alcohol and petrol, the engines being specially adjusted for the purpose.

Agriculture in this and other countries is suffering severely from the present economic conditions. If the production of pure alcohol on an extensive scale can be made worth while, then it should prove a great boon to agriculture, for through agriculture, carbohydrates, the raw material for alcohol production, can be grown cheaply and in large quantities.

PRACTICAL WORK

1. Demonstrate the process of respiration in plants.

There are several methods of doing this, the best depending upon the production of carbon dioxide during the process. The following are suggested methods, though it is not proposed that all the experiments should be attempted.

(*a*) Soak some pea seeds in cold water for twenty-four hours. The seeds will absorb some of the water and are then ready for germination, which demands the expenditure of much energy. Consequently, respiration is particularly high in soaked seeds. Fill a wide tube with lime-water and place this inside a larger bottle. Then put some of the soaked peas in the bottle and tightly cork it (Fig. 178).

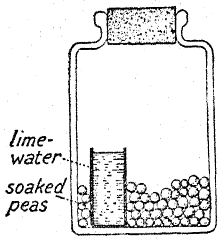


FIG. 178. EXPERIMENT FOR DEMONSTRATING AEROBIC RESPIRATION.

Lime-water is turned milky by the absorption of carbon dioxide. Therefore, leave this apparatus for about twenty-four hours, then record and discuss the results.

(*b*) Collect a large number of heads of living flowers and push them down into the spherical part of a flask. Then invert the flask over a dish of mercury, so that the mouth is below the surface. Now, by means of a bent tube, allow some strong caustic potash solution to rise to the surface of the mercury inside the neck of the flask (Fig. 179).

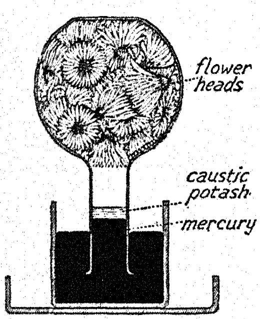


FIG. 179. EXPERIMENT FOR DEMONSTRATING AEROBIC RESPIRATION.

After a few hours, the mercury will rise inside the flask. This can be explained by the respiratory activity of the flowers. During the process, oxygen is absorbed from the enclosed atmosphere of the flask, and an equal volume of carbon dioxide is given off. Therefore, there should be no change in the volume of the atmosphere in the flask. But caustic potash dissolves carbon dioxide easily. Hence the reduction in volume of the atmosphere of the flask.

Record this experiment and discuss the results.

(*c*) Set up the experiment as shown in Fig. 180. By means of gummed paper, mark the level of the mercury in the tube at hourly intervals. Record and discuss the results.

(*d*) Set up the apparatus shown in Fig. 181. Great care must be

taken that all the connexions are air-tight. This can be done by smearing with vaseline. Then draw air slowly through the apparatus by fixing the end indicated, to a filter pump. If such a pump is not available, remove the soda-lime tube and fix the end, indicated in Fig. 182, to the apparatus in place of the soda-lime tube. Fill the very large upper vessel with water and then turn on the tap slowly. By this means, air will be forced through the apparatus.

After a time, notice that although the lime-water, through which the air current bubbles *before* passing through the soaked

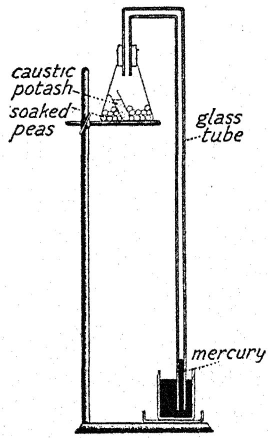


FIG. 180. EXPERIMENT FOR DEMONSTRATING AEROBIC RESPIRATION.

peas, remains clear, that through which the current bubbles *after* having passed through the soaked peas becomes milky.

Realising that soda-lime and caustic potash absorb carbon dioxide, fully explain these results, first of all from the chemical point of view. Then discuss them from the point of view of respiration.

2. Show that respiration takes place both in the light and in the dark.

Perform any of the experiments suggested in Experiment 1 in the light and in a dark room, and compare the results.

3. Show that normal plants can respire for a time in the absence of oxygen (anærobic respiration).

Fill a test-tube with mercury and, sealing the end with the finger, invert it over a dish of mercury, with the mouth of the tube

below the surface. Then, by means of the fingers, insert some soaked peas, one at a time, into the mouth of the tube. These

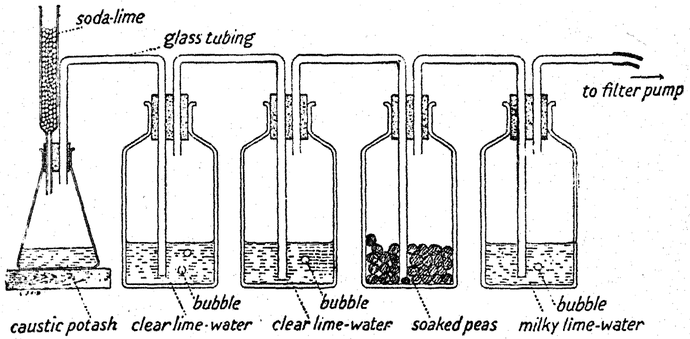


FIG. 181. EXPERIMENT FOR DEMONSTRATING AEROBIC RESPIRATION.

peas will rise to the top of the tube (Fig. 183). Support the tube in this position by means of a clamp.

After about twenty-four hours, the peas will have given off a gas

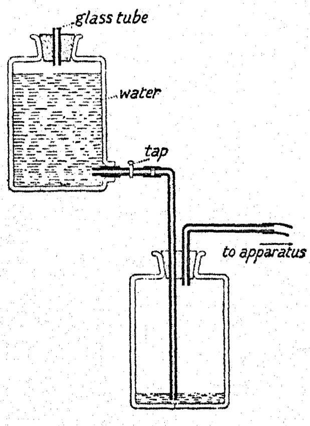


FIG. 182.

which has forced the mercury some distance down the tube. The gas can be shown to be carbon dioxide by allowing a little strong caustic potash solution to rise into the test-tube from a bent tube inserted at the mouth. The potash, now in contact with the

carbon dioxide, absorbs it, and the mercury rises again in the tube.

Record these results and discuss them.

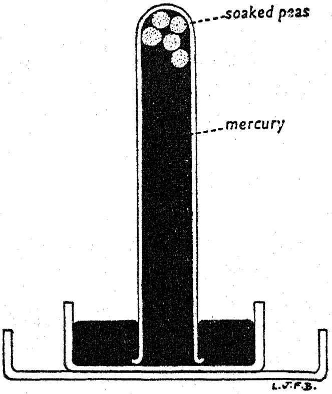


FIG. 183. EXPERIMENT FOR DEMONSTRATING ANAEROBIC RESPIRATION.

4. Show that energy, in the form of heat, is liberated during the process of respiration.

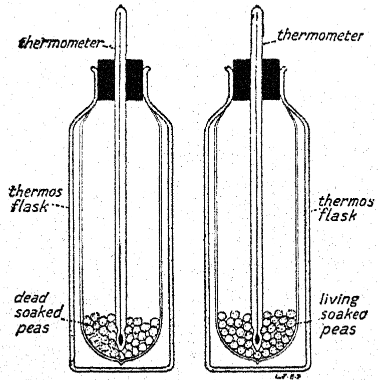


FIG. 184. EXPERIMENT TO SHOW THAT HEAT IS LIBERATED DURING RESPIRATION.

Choose some soaked peas, then divide them into two groups of equal numbers. Place one lot in a thermos flask into which a

thermometer has been inserted, making sure that the stopper is tight (Fig. 184). Put the other lot of peas in boiling water and boil them for about ten minutes. Remove them and allow to cool down to the normal temperature. Then treat them as the first lot. By boiling the peas, they have been killed.

After a day, remove the thermometers and record the temperature indicated by each. Realising that only living things can respire, explain the results obtained.

The evolution of heat by plant material can also be demonstrated in a manner representing the 'sweating' of hay.

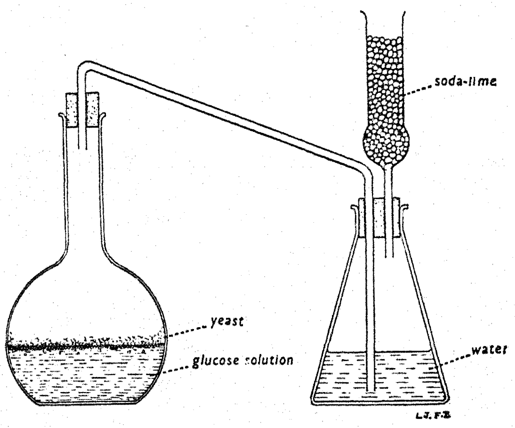


FIG. 185. APPARATUS FOR PREPARING ETHYL ALCOHOL.

Fill a pail with cut grass, pressing it down firmly. Then insert a thermometer in the grass. Record the temperature periodically for several days.

Wounding a plant causes an increase in respiration and consequently an increase in the evolution of heat. To what extent the heat given off by cut grass is due to normal respiration of the cells and to wounding has not been determined.

5. Examine some yeast cells under the microscope.

These cells are rather small, so great care is needed. Mount a little in water and examine under the low power. Look for examples of budding. Then, under the high power study the structure of a yeast cell in detail, noting especially the intranuclear vacuole. This is not easy, and a specially prepared, stained slide of yeast is to be recommended.

6. Make a preparation of ethyl alcohol by the activity of zymase on glucose.

Prepare a weak glucose solution and put into a flask. Introduce a little yeast into the solution, then connect the flask to a second flask as shown in Fig. 185.

Keep a running account of the experiment during the next few days. Notice that the yeast increases, giving a frothy appearance to the solution. Periodically, too, bubbles of carbon dioxide are given off from the end of the bent tube in the second flask. This carbon dioxide is absorbed by the soda-lime.

CHAPTER XIV

IRREGULAR NUTRITION AND DISEASE

THOUGH the normal nutrition of plants and animals is of the utmost importance to science and the well-being of civilised man, irregular forms of nutrition, of which there are many, are equally as important, especially from the point of view of agriculture, horticulture, veterinary science and medicine.

The regular form of nutrition in the plant is by photosynthesis. In the animal, it involves chiefly the consumption of plant and other animal material. Many plants and animals, however, do not obey the normal rules of nutrition, and such organisms, though in many cases useless but **harmless**, in many others they are **useful**, and in others very **harmful** owing to their irregular mode of life.

Parasites

Animals either consume plants or animals, dead or alive; but, whichever it is, very soon after the victim is consumed it dies. There are, however, many animals which never obtain their food in this normal fashion. Instead, they attack other animals and absorb part of their victim, leaving the victim still alive. More often than not, such animals attack a victim and live on it, either externally or internally, without killing it. As the victim consumes its food normally, the attacking animal absorbs some of this food from its victim.

An animal which lives on another in this irregular manner is called a **parasite**, and the victim on which it lives is referred to as the **host**. Animal parasites of this nature may be beneficial to the host, or they may be perfectly harmless though useless, or—and this is much more common—they are very harmful.

Harmful animal parasites are responsible for many well-known

diseases, both in the lower animals and in man. Sometimes the host recovers from its disease by getting rid of the parasite in some way. Very often, on the other hand, the parasite kills the host.

Many well-known plants do not contain even a vestige of chlorophyll, and it is therefore quite clear that they cannot live normally by photosynthesis. On the other hand, they carry on a very irregular form of nutrition. Some such plants are parasitic on animals. Plants of this nature usually cause disease to the hosts concerned. Other plants are parasitic on other plants; so here we have a plant parasite on a plant host. This type of parasitism underlies the majority of plant diseases, which cost the agricultural and horticultural industries of the world many millions of pounds each year.

Saprophytes

There are many other plants, some of which are well known, which do not resort to such drastic methods for their irregular form of nutrition. These plants are not green, and therefore must obtain their food already manufactured for them. But, instead of attacking living plant or animal hosts, they live on the decaying material of dead plants and animals. It is quite clear that when an animal or a plant dies, in the dead material left behind there must be quantities of carbohydrates, proteins, fats, etc., present. The plants in question absorb these foods. Plants which live on decaying dead material are therefore not classified with parasites. They are placed in a group by themselves, and are called **saprophytes.**

It must be clearly understood from the beginning that it will be impossible to consider more than a small fraction of each type. A consideration of parasites in animals will give some idea of how widespread this phenomena is through the whole kingdom of life as we know it to-day.

Animal Parasites on Animal Hosts

Certain animals are parasitic on other animals. One very important parasite of this type is the parasite which, through its parasitic habit, causes the well-known disease called **malaria.** This disease is caused by a microscopic organism, commonly re-

ferred to as the malarial parasite, which lives in the blood-vessels of man. There it lives on the substance of the blood, thus causing the disease.

This is a very important parasite, since it is very wide in its distribution and probably causes more illness and death than any other disease, to which both military people and others who have lived in tropical regions will testify. The late Sir Andrew Balfour estimated that the cost of malaria to the British Empire alone is about £55,000,000 annually.

Until recent years, little was known about this parasite, especially how it managed to get into the blood of its victim. At that time, the parasite made it impossible for the white man to live in certain parts of Africa. Then, towards the end of last century, **Sir Patrick Manson** and **Sir Ronald Ross** carried out some very important work on the problem, and showed that the parasite has to pass part of its life-history in the body of a mosquito. These mosquitoes usually develop in stagnant water, and thus, by the destruction of such breeding places, or by pouring oil over the water, the spread of malaria by the mosquito has been controlled to a great extent. In this way, certain parts of Africa, until quite recently referred to as "the white man's grave" owing to their being infested with malaria, have now been made quite healthy regions.

Of the multicellular parasitic animals there are, unfortunately, all too many. Their hosts are often domestic animals, such as the cow, sheep and pig. Multicellular animal parasites also live parasitically on other edible animals, such as fish. Worse still, certain types use man as their host.

One common example is the **tapeworm.** This is a long, flattened animal which lives in the intestine of man.

Animal parasites, however, sometimes have their uses. For example, insects are the unwilling hosts of many different animal parasites. Certain of these parasites cause the death of their insect host. Now a large number of these insect hosts themselves are dreadful scourges where plants are concerned. They attack plants parasitically, with the result that tremendous areas of cultivated plants of all descriptions are ruined. One way of preventing this would be to try and get the parasite to

attack its insect host, and thus destroy the insect before it can, in its turn, destroy the plants. This has been tried in many cases. To-day, it is a very popular method of dealing with certain crop diseases in the tropics. Agriculturalists in the tropics, who have to deal with many different kinds of crops, have even gone so far as to import large numbers of certain parasites for the purpose of attacking such diseases. The effect has been excellent, involving the saving of millions of pounds sterling in many cases.

Plant Parasites on Animal Hosts

Apart from the great group of bacteria, comparatively few plants are parasitic on animal hosts. There are some, however, and what there are have proved, and are still proving, very troublesome.

All such parasitic plants are colourless, that is, they contain no chlorophyll, and nearly all of them belong to the fungi. Being colourless, they cannot manufacture their own food, therefore they attack their animal hosts, chiefly in order to absorb manufactured food from them.

Certain strains of yeasts attack the blood-system of some of the lower animals, and from the blood of their hosts they absorb the food they require. Their parasitic habit often results in the death of their host.

Many sportsmen who are keen on fishing are familiar with the terrible disease which attacks salmon, often causing so much havoc amongst that fish that some rivers, well-known for their salmon-fishing, are at times scarcely worth the trouble taken over the sport. This disease has been known for about a century and is caused by a fungus called *Saprolegnia*. This fungus attacks its host, the salmon, at its gills. There, the fungus grows by absorbing nutrition from its host. Finally the growth of the parasitic *Saprolegnia* achieves such dimensions that the gills cannot carry on their work, that is, breathing. Thus the fish is killed by a form of suffocation. This disease often breaks out into such terrible activity that an epidemic occurs, and thousands of the salmon are killed in one season.

Ringworm, a skin disease in man, is also caused by several forms of Fungi.

Bacteria

The great group of bacteria contains many parasitic types. It must *not* be imagined, however, that because many bacteria are parasitic therefore they *all* are. This is far from being the case. *Quite a large number of bacteria are free-living and harmless*; *others are free-living and distinctly useful, especially from man's point of view*; for example, the nitrogen-fixing bacteria which were considered in Chap. VIII. Certain bacteria are used in the 'curing' of tobacco. Other bacteria are used in the disposal of sewage, and also in various industries, such as baking and brewing. So, although bacteria have a very bad name in causing a large number of diseases in animals, including man, also in causing havoc in certain industries, such as in the weaving of fabrics, it must be realised that not all bacteria are 'tarred with the same brush.' In fact, one can safely say that there are just as many useful bacteria as there are harmful. *Man depends on the useful bacteria almost as much as he is crippled by the harmful types.*

All bacteria are unicellular plants. They exist in different forms, but in all cases they are single cells which contain no chlorophyll. The cells of bacteria are some of the smallest known to science.

In view of the absence of chlorophyll, all bacteria are forced to be either parasitic or saprophytic. The parasitic types are the most important to man. By attacking certain tissues in the human body, and especially the blood, they are the cause of many well-known diseases. For example: **erysipelas, meningitis, diphtheria, tuberculosis** (consumption), **anthrax, typhoid fever, dysentery, cholera,** various plagues, and **tetanus** (lock-jaw) are just a few of the diseases of man caused by the parasitic activities of various bacteria (Fig. 7).

Until about seventy years ago it was not really known how bacteria were formed. People believed then that bacteria were produced from putrefying plant and animal matter. In other words, they thought that living plants were generated from dead material—a belief that we nowadays should hold untenable. This sudden springing up of life was called **spontaneous genera-**

tion. But the great French scientific worker, Louis Pasteur, investigated all ideas of spontaneous generation and showed they were unproved. Pasteur did much work in fermentation, etc., but in 1864 he made his name immortal by the announcement that bacteria are not spontaneously generated from putrefying material, but are spread about the earth either themselves or by means of spores, somewhat similar to those of yeast, though much smaller. This immediately led to the recognition of why diseases can be infectious, thus causing a healthy person to be attacked by a disease, without necessarily coming into actual contact with a diseased person. The disease is spread by means of the bacteria floating in the air, or, even more, by the lighter bacterial reproductive spores.

The means whereby plant and animal diseases can be spread are manifold. Contact with an infected organism is the simplest, but some disease-causing organisms, especially bacteria, can be conveyed by wind, and over many miles of sea by ships. The aeroplane is now coming under suspicion as being a means of conveying disease into countries where it was hitherto unknown. To what extent the disease-carrying possibilities of the aeroplane may develop, unless studied and checked by science, can be gauged by progress in aviation itself.

The question of paramount importance is: How do the disease bacteria get into their hosts ? This can take place in one of two ways. The bacteria or their spores can enter through an open wound (that is why wounds should be kept clean and well-bandaged), or they can get in through the nose and throat. The breeding and spreading of bacteria can be curtailed by keeping homes, streets, buildings and even our own persons clean, by sneezing or coughing into a handkerchief, and by isolating disease-stricken patients. A well-known method of counteracting contagion is by putting people, disease-stricken, or suspected of a disease, into quarantine.

Bacteria and Antiseptic Surgery

Until comparatively recently, parasitic bacteria took a heavy toll of lives of people during surgical operations. Naturally a surgical operation involves a wound, and, in the early days,

bacteria soon entered since they, or their spores, are constantly present in the atmosphere. The cause of death was usually a parasitic bacterium which set up blood poisoning.

Blood poisoning during an operation, so common a few decades ago, is scarcely ever known now. This is due to the great scientific work of the British surgeon, **Joseph Lister**, who was born in Essex, in 1827. While on the staffs of the University of Glasgow and, later, King's College, London, Lister experimented with carbolic acid and found that it prevented bacteria from entering surgical wounds and setting up septic poisoning, by killing the bacteria. This work he developed to a great extent, and thus introduced what is now called **antiseptic surgery**, thereby saving millions of lives during surgical operations throughout the world. For this great work Lister was raised to the peerage in 1897, and is therefore more familiarly known as Lord Lister.

The antiseptic surgery of Lister, introduced about fifty years ago, has since been much modified. Carbolic acid is not often used now; but the fundamental fact is the same, that is, to prevent the parasitic activity of those dreaded disease-carrying bacteria. Antiseptic surgery means placing an antiseptic substance on the wound to prevent bacterial entry. Nowadays, surgery is not only antiseptic, but also **aseptic**. This means that all efforts are made to prevent any bacteria or their spores being anywhere near a wound, thus eliminating the necessity for killing them. This is done by keeping operating theatres scrupulously clean and sterilising (that is, so treating a thing with various solutions or heat that any living thing present on it will be killed) all instruments, dressings and even the surgeon's and nurse's hands. Rubber gloves are used for preventing any bacteria, etc., passing from the patient to the surgeon or vice versa, and masks are worn over the mouth by the nurses and surgeon, in order that they may not breath any bacteria on to the patient or, on the other hand, inhale bacteria from the patient.

Virus Diseases

Much more recently, worse infective agents of disease have been discovered. These are very difficult to investigate, and,

indeed, though a great deal of research is being carried out on them at present, we know comparatively little about them. The reason why such agents of disease are so elusive of investigation is that they are so small, being much smaller than bacteria. It is very difficult to say whether they are living things or merely non-living chemical substances. These substances are called **viruses**, and are responsible for many dreaded diseases in plants and animals, more especially the latter.

FIG. 186. VIRUS DISEASES IN PLANTS.
Left, yellow mosaic in tomato ; right, a virus disease in tobacco.
(*Photos. kindly supplied by Dr. Redcliffe N. Salaman, Director of the Potato Virus Research Station, School of Agriculture, University of Cambridge.*)

The first virus discovered was that responsible for the disease called **foot-and-mouth disease** of cattle. The virus which causes this disease was discovered by **Loeffler** in 1898.

Now, much work is being done on viruses, for they are very important, being responsible for such diseases as foot-and-mouth disease, **yellow fever, rabies, cowpox, dengue, smallpox, mumps**, etc. It has been suggested that influenza and even cancer may be caused by these ultra-microscopic viruses, but, unfortunately, nothing has been conclusively proved yet.

It is now realised that viruses are responsible for certain plant diseases, and that viruses are probably more devastating than bacteria, in the case of plants. The first plant virus was discovered by **Iwanowski** in 1892, who showed that the **tobacco mosaic disease** (a disease which attacks the leaves of the tobacco plant and causes much havoc amongst the crops) is caused by a virus.

Many other plants suffer from mosaic diseases, such as the potato, sugar-cane, tomato, bean, pea, clover and so forth. They are all caused by viruses, and the first symptom is the appearance of white or coloured patches on the leaves (Fig. 186). Whereas in some cases the disease scarcely goes any further than this, and thus causes little damage, in others it causes the whole plant to be affected and sometimes destroyed. The trouble is that such mosaic diseases are very infectious. Much work is being done at the present time on plant virus diseases, especially in the research stations connected with the plantations which suffer from them, and also at the **Rothamsted Experimental Station** in Hertfordshire and at the University of Cambridge.

Animal Parasites on Plant Hosts

Animal parasites on plant hosts are usually very small types, such as insects and certain worms, etc. **Aphides** are familiar insect parasites in the garden and greenhouse. The **green aphis** attacks many greenhouse plants. The **black aphis** attacks broad beans, sometimes completely covering the young shoots, making them appear black. Locusts, and their disastrous effects on vegetation, especially in Egypt and the Near East, have been notorious since pre-Biblical days.

To-day thousands of insect pests are recognised, causing great damage to crops. Much money and time are being spent on dealing with them; but, unfortunately, this is necessary.

A great pest of the potato, common in the United States and South America, is the Colorado **potato beetle**. An example of how diseases can be conveyed from one part of the world to another is shown by this pest, which has now spread over nearly a third of France, having been brought over unwittingly by American

troops or supplies during the War. German scientific workers are now visiting the French infected areas in anticipation of an eventual invasion of Germany by this unfortunately introduced plant pest.

The **eel-worm**, which attacks several crop plants, chiefly through the roots, is another all too prevalent animal pest.

Plant Parasites on Plant Hosts

Of more immediate interest to us, as botanists, are those plants which are parasitic on other plants. These are not only interesting, but many such plants are also of the greatest importance to agriculturalists and horticulturalists all over the world.

All real parasitic plants which have plant hosts are colourless; but not all are fungi. There are several more advanced plants, even flowering plants, which are parasitic. In many cases the parasite kills its host, in others the parasite causes disease, so that the host becomes deformed, or its growth is curtailed, or its production of fruit very much reduced. There are some plant parasites, however, which scarcely affect their plant hosts at all.

Bacteria in Plants

Certain bacteria are parasitic on plant hosts, thus setting up disease in the host. For example, the **fire blight** of apples and pears is caused by parasitic bacteria.

Fungal Parasites in Plants

Many well-known plant diseases are caused by certain fungi. One very familiar example to all potato growers is the **potato blight**. This is caused by a parasitic fungus called *Phytophthora infestans*. This plant is a colourless, multicellular plant, composed of long threads, much finer than those of silk, known as **hyphæ**. The spores attack the host, the potato plant, through the stomates of the leaves (Fig. 187). Once inside the leaves they develop and send out long hyphæ, which penetrate the cells of the leaf and extract food from them (Fig. 188). The result is that patches of a pale green colour appear in those parts of the leaves where the hyphæ are carrying on their parasitic life (Fig. 189).

Eventually these patches turn brown because the cells of the leaf which are attacked are killed by the activity of the parasite. The hyphæ of this parasite grow throughout the plant and eventually get into the tubers themselves. Here they penetrate the cells to extract foods, eventually causing such cells to rot and thus making the tubers unfit for human consumption.

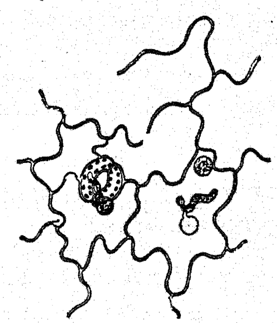


Fig. 187. Surface View of Part of a Potato Leaf attacked by Spores of Potato Blight.

The spores are just beginning to develop and penetrate through the stomates. Highly magnified.

(*After Marshall Ward.*)

Potato blight is a comparatively new disease. It was first noticed in Europe and North America in 1840. In 1846 it assumed widespread activity in Ireland, and caused such a dreadful failure in the potato crop that famine ensued, since that country depends so much upon potatoes for food. Wet seasons are usually favourable to the disease, probably because the spores of *Phytophthora* thrive in a humid atmosphere.

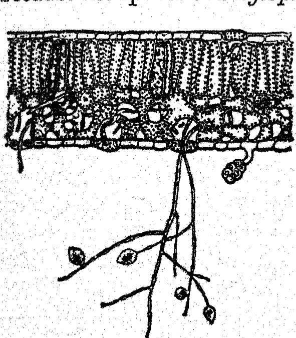


Fig. 188. Section of Part of a Potato Leaf infested with Hyphae of *Phytophthora infestans*.

A reproductive hypha is growing out through a stomate.

(*After Marshall Ward.*)

Some plant parasites, such as those which cause diseases known as rusts, have two hosts on which to complete their life-history. Plant rust diseases are very common among grasses and cereals, such as wheat and maize.

A rust, very well known to farmers, is the rust of wheat caused by the fungal parasite called *Puccinia graminis*. This attacks the leaves of the wheat plant, causing coloured patches to appear on them (Fig. 190). Then it produces several types of spores. One type is shed on to the soil, where the spores remain during

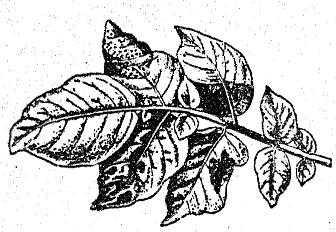


FIG. 189. POTATO LEAF ATTACKED BY *Phytophthora infestans*.
(*After Sorauer; from Marshall Ward.*)

the winter, and attack the wheat again in the next season.

Another type of spore cannot develop unless it is on a new host. This host is the familiar ornamental bush known as **barberry** (*Berberis vulgaris*). The spores develop on this plant and produce more hyphæ on the leaf, which cause yellow patches on it (Fig. 191). From these hyphæ new spores are formed again, which attack the former host, the wheat.

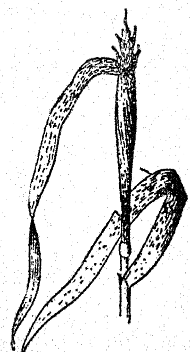


FIG. 190. UPPER PORTION OF THE STALK OF WHEAT PLANT ATTACKED BY *Puccinia*.
(*After Marshall Ward.*)

Thus, it is quite clear that this parasitic rust disease can be very much curbed by making sure that the second host, barberry, is not growing anywhere near the wheat. For this reason, in certain parts of the great wheat-growing regions of Canada, the United States and the U.S.S.R., it is illegal to grow barberry, even as an ornamental shrub in a flower garden.

Parasitic Flowering Plants

Apart from the many parasitic fungi which attack plants, there are several parasitic plants of the higher groups.

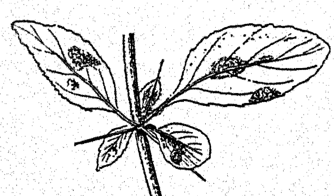


FIG. 191. LEAVES OF BARBERRY ATTACKED BY *Puccinia*.
(*After Marshall Ward.*)

One well-known example is the **dodder** (*Cuscuta europæa*). This is a flowering plant, but it is absolutely devoid of chlorophyll. Therefore it has to resort to irregular methods of obtaining food. Its hosts are clover (*Trifolium pratense*), gorse (*Ulex*

europæus) and heather (*Calluna vulgaris*), etc. The dodder has a yellowish, thread-like stem which twines round the stem of its host (Figs. 192 and 193). At intervals up the stem, the parasite sends off suckers or **haustoria** which penetrate the stem of the host until they tap the vascular bundles containing the food, and, by means of the haustoria, food is extracted from the host plant. Natur-

FIG. 192. DODDER PARASITIC ON THE STINGING NETTLE.
(*Photo. Henry Irving.*)

ally, this being the case, one would not look for leaves on the dodder itself. Nevertheless, they are there, but since they are not required as photosynthetic organs, they are reduced to colourless scales. The flowers of the parasite are produced in rosette-like bunches, and are pink in colour. This parasitic flowering plant is rather common in meadows, and especially where clover is grown for fodder. It does not usually kill its host, for the host manages to manufacture enough food, in its leaves, to supply both itself and the parasite.

One particularly interesting example of a thoroughly parasitic flowering plant is that called *Rafflesia*. There are several species, all of which are native to Malaya. This plant is parasitic on the roots of vines. It is parasitic to such an extent that the whole of the plant body, including stems, roots and leaves, are all reduced to colourless straggling threads which grow through the soil and pierce the roots of their vine host and extract food. The flower, on the other hand, is far from reduced (Fig. 194). The species known as *Rafflesia Arnoldi* has the largest known flower in the world, being usually a brilliant red in colour, measuring 30 inches across and weighing 15 lb. It has a repulsive smell, like that of decaying fish.

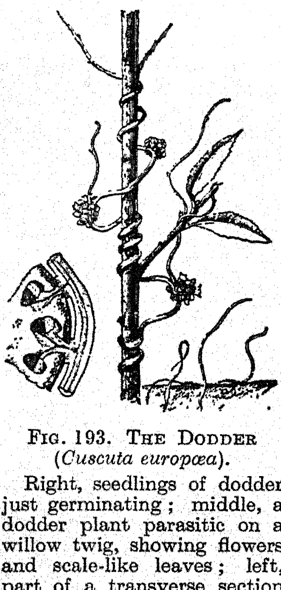


FIG. 193. THE DODDER (*Cuscuta europœa*).

Right, seedlings of dodder just germinating; middle, a dodder plant parasitic on a willow twig, showing flowers and scale-like leaves; left, part of a transverse section of the willow stem showing the haustoria of the dodder stem penetrating to the vascular bundles.

(*After Noll.*)

Treatment of Plant Diseases

Flowering parasites are not common, and they are not very troublesome. On the other hand, the fungal parasites which live on plant hosts are a very expensive nuisance, as many farmers and gardeners well know. Such parasites very often succeed in killing their hosts, the crops, thus involving much trouble. They cause tremendous damage throughout the world to all kinds of crops. Naturally, it is best to be able to prevent the disease and, up to a point, this is done. But it is not always very easy.

Such diseases are sometimes prevented by such methods as soaking the seeds in certain solutions before planting. The best method so far, however, is to destroy all plants which are attacked, as soon as it is found that they are diseased. This is usually done by burning. Of course, this is only possible so long

as every person who notices any kind of plant disease destroys the plant at once. For example, there is no cure known at present for the potato wart disease. Therefore, to prevent this from spreading, it is best to destroy completely all plants which are found to be attacked by this parasite. To make sure of this, the State often takes a hand in the matter, through the agency of the police.

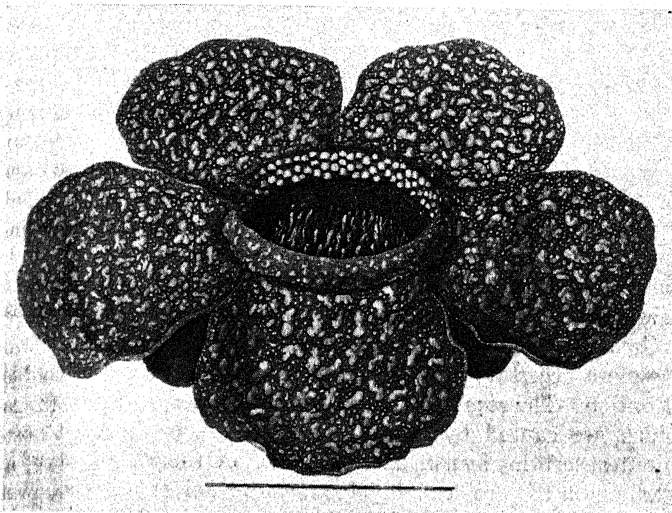


FIG. 194. FLOWER OF *Rafflesia Arnoldi*.
The scale represents 12 inches.
(*British Museum.*)

Prevention and cure of disease is still further possible in certain cases. For example, the potato blight, if caught in its early stages, can be curbed in its ravages, even if it is not completely prevented. This is done by spraying the infected leaves with a chemical solution called **Bordeaux mixture.** This mixture is made up of 4 lb. copper sulphate and 4 lb. quicklime to 50 gallons of water, to which 2 lb. of lead arsenate has been added. Bordeaux mixture is very familiar to potato growers. In spraying, care should be taken that the mixture gets on the under surface

of the leaves, since the fungus attacks the leaves through the stomates, which are chiefly on the under surface.

There are several kinds of spraying mixtures for combatting plant disease. Bordeaux mixture is one ; formalin solution and nicotine solution are others. Such spraying mixtures are used extensively on fruit, vegetable, tea, rubber, etc., plantations.

Importance of Plant Diseases

The amount of damage that plant parasites, in the form of such types of fungi as have been examined, do to plant hosts of economic importance is nothing short of appalling. It involves farmers and various Governments in expense which extends to millions of pounds sterling each year.

Wheat and potatoes need a great deal of attention, as has already been seen. But this is only a small fraction of the total. In the tropics, and especially the British Empire overseas, many plants are grown in extensive plantations for economic purposes. Nearly all such plants are subject to the attacks of parasites, which have to be dealt with by responsible people.

Great Britain is a very important agricultural country. It is therefore necessary that all crops should be given the closest attention. The result is that all plant diseases, the majority of which are caused by fungal parasites, are subjected to the minutest scrutiny by men of science, some of whom are constantly working on the problems involved, at our universities, colleges, and research stations. In fact, the Government of Great Britain and, indeed, those of most civilised countries make grants running into thousands of pounds annually for the purpose of this work. The department of the Government which fosters work of this nature is the Ministry of Agriculture and Fisheries. In Scotland there is a corresponding Board.

The result of such administration is the periodic publication by the Ministry of results of research work. These publications can usually be obtained from His Majesty's Stationery Office. As diseases appear, reports and advice are published. Also, agricultural advisers are sent out into country districts to give lectures and advice to farmers and others connected with agriculture. When a disease, whether of plants or animals, becomes

very serious, sometimes the police have to take a hand, especially in seeing that all cases are reported, where necessary. This is a very important step, because some people are naturally reluctant to make a report, since it often means expense in dealing with the disease, and perhaps even in destroying the diseased plants or animals. For example, any potato crop attacked by the potato wart disease (*Synchytrium*) must be reported immediately to the local police authorities. In the case of animals, the terrible foot-and-mouth disease of cattle must be immediately reported. This often results in the destruction of the infected animals. Even healthy cattle must not be removed from place to place during an epidemic. This has often resulted in certain agricultural shows being abandoned. But it is all for the common good, though a big expense.

Research Stations throughout the Empire

Apart from the work being done in universities on plant and animal diseases in Great Britain, there are many stations where research into these problems concerned is the order of the day. For example, the Agricultural Experimental Station at **Rothamsted** in Hertfordshire does much good work on plant diseases under the direction of **Sir John Russell.** Then there is the **Imperial Mycological Institute** at Kew, Surrey. This is concerned with fungal disease chiefly (mycology is the branch of botany dealing with fungi, especially parasitic ones). This institute is directed by another well-known scientific man, **Dr. E. J. Butler.** Here plant diseases all over the British Empire are carefully examined and reported upon. At the **Long Ashton Fruit Research Station,** near Bristol, much work is done on the diseases of fruit trees, especially apples, plums, and pears, and also on the willow. Fruit and flower diseases are dealt with at the Horticultural Research Station at **East Malling,** in Kent.

The ravaging effects of fungal parasites on plant crops are taken just as seriously in the British Empire overseas. A brief survey of the effects of plant diseases in the Empire will give some idea of their importance.

In the great tropical and subtropical countries, industries

such as tea, rubber, coffee, cocoa, banana, orange, lemon and other fruit planting involve the occupation of millions of people. Prior to the coming of the white man in these regions, the native used to cultivate his land in a very haphazard and non-scientific way. As an Indian proverb says, "The cultivator's ways and the sheep's ways tend to be the same." Little use was made of scientific knowledge in such cultivation. For example, towards the end of last century, the coffee plants in the plantations of Ceylon were attacked by a fungal parasite, through their leaves. Nothing was done about it, however, until 1880. Then the great botanist, Professor Marshall Ward, was sent for, but he arrived in Ceylon too late to save the crops from ruin. Here is a very clear example of the result of not taking the disease and dealing with it immediately it is detected.

Twenty-five years ago, diseases broke out in the Indian food plants, rice, sugar-cane and palmyra palm, in epidemic form. But the botanists attacked the problem immediately. Treatment was drastic. In the case of the palmyra palm, which, by the way, is used for food, for distilling a certain drink and for supplying canes for wicker work, nearly a million trees were cut out in order to save the rest. It was also found that by removing the bud sheaths, the spread of the disease was prevented. This treatment in India cost the Government £20,000 in 1921 alone, but in the same year the value of the palms saved was estimated at £28,000, and since then the number of palms saved must run into millions.

In many other cases, especially in the case of rice, diseases used sometimes to become so rampant that the crop was not worth gathering. Sometimes even to-day it is found that there is nothing for it but to get rid of the crop altogether and to change the variety, because some variety of rice, as in other plants, is susceptible to a certain disease, whereas another variety of rice is more or less immune.

It has already been seen that one way of dealing with plants diseased by fungal parasites is to spray them with certain chemical solutions which kill the parasite. This sounds a good method ; but the trouble is that there are very few chemicals which will kill the fungus without killing the host as well.

Therefore, man is very limited in his choice of fungus-killing substances, which are called **fungicides**. The two best types of fungicide are those which contain either sulphur or copper in some form or other.

Millet, a cereal, is one of the staple foods of the Indian people. Until recently, in the Bombay Presidency alone, certain rust diseases of this plant cost more than a million pounds annually. Now this is being very much reduced by the use of certain fungicides. In southern India another crop, the **areca palm**, is attacked by a fungal parasite, closely related to that which causes potato blight. As in the case of the latter, therefore, spraying with Bordeaux mixture was tried, and now the gain from spraying is estimated at more than £100,000 each season.

Parasites which are formidable pests in one country are sometimes found to have very little effect on the same crop in another. For example, in the Sudan, there has recently been a great epidemic of fungal disease in the cotton areas. A great irrigation scheme was opened there in 1925, and, whereas before this area was sparsely populated and famine-stricken, now it is peopled by nearly 200,000 people, who have gone there to grow cotton on the irrigated land. There is one cotton plantation in the Sudan with an area of 600,000 acres—probably the biggest farm in the world.

An Egyptian variety of cotton is used there, but the trouble lately has been that this variety is attacked by a certain variety of fungal parasite. This parasite is very potent in the Sudan, yet in Egypt it has scarcely any effect. The drastic effects of the parasite can be seen by the returns published of the crop. In the year 1926 the amount of cotton produced in the Sudan was 479 lb. per acre. The disease became worse and in 1931 the returns showed 129 lb. per acre—a terrible loss. Actually it involved a loss of 60 million pounds of cotton in the Sudan in 1931, representing a cost of £800,000. But, thanks to the men of science, the trouble is subsiding, for they found that the disease was being conveyed from one generation of plants to another through the seed. In other words, the parasite actually passed into the seed. It was therefore decided to disinfect the seed before sowing, and in 1932 the result was that the yield rose to 400 lb. per acre.

Another British possession where plant diseases are of great importance is Jamaica. This colony is noted for its bananas. In 1930, 24 million bunches were exported. In 1912 the great parasitic disease of the banana known as **Panama disease** was first noticed. This developed to an appalling extent and great plantations had to be completely abandoned, thus forcing many workers to leave the country and causing distress among those left behind.

Panama disease is due to a soil fungus. It is still rampant in certain banana plantations of the world, and is costing various countries millions of pounds each year. No cure has been found, but work is being done especially at the **Imperial College of Tropical Agriculture** in Trinidad to find a variety of banana which is better able to resist this troublesome disease. Even to-day, botanists are touring the world in an endeavour to find a suitable variety of banana. The varieties chosen are sent to the **Royal Botanic Gardens** at Kew, Surrey, where they are tried out under the direction of **Sir Arthur Hill**. Then they are sent on to Trinidad.

So important are plant diseases that our colonies must keep up their teams of scientific workers to tackle the problems as they come along, just as much as the mother country does. A few places are worth mentioning to give some idea of the amount of work involved. Only a few, however, can be mentioned, for there are so many of them to-day. The following research stations deal chiefly with the crops mentioned : **Central Experimental Farm, Ottawa,** cereals and forage crops ; **Dominion Rust Laboratory, Winnipeg,** cereal rust diseases ; **Council for Scientific and Industrial Research, Australia,** cereals, vines, oranges, lemons, grape-fruit, tobacco ; **South Africa, Union Department of Agriculture,** oranges, lemons, grape-fruit, cereals, tobacco, cotton, pineapple, olives, coffee, flax, hops, vines ; **India, Central Cotton Committee,** cotton ; **Burma,** various research stations, rice, cotton, wheat, beans, sugar, coco-nut ; **Ceylon, Rubber Research Scheme,** rubber, and **Tea Research Institute,** tea ; **Cyprus, Department of Agriculture,** vines ; **Trinidad, Imperial College of Tropical Agriculture,** bananas. Other nations are carrying out similar work.

Plant Saprophytes

Saprophytic plants are of very common occurrence in nearly all parts of the world. Though some of them are troublesome, naturally none of them are such dreadful scourges as are many plant parasites, for they never attack *living* organisms. Since they never contain chlorophyll, their method of nutrition is an irregular one, namely, by extracting food from decaying plant and animal material.

A few flowering plants are of saprophytic habit. For example, the **bird's nest orchis** has no green leaves. The leaves are reduced to sickly yellow scales. The plant derives much of its nutrition from decaying leaves and other humus in the soil, chiefly of densely shaded beech woods. It also contains a mycorrhizal fungus.

The majority of saprohpytes are bacteria and fungi. Many types of saprophytic bacteria live on decaying plant and animal material, and by their chemical action cause the putrefaction of the decaying substance. Such bacteria are called putrefying bacteria.

A very familiar type of saprophytic fungus is the group collectively called **moulds**. They live on different types of food-stuff, and when they appear the food-stuff is often referred to as being 'mouldy.'

One very familiar mould is called *Mucor*. There are several types of this plant. One type lives on decaying horse and other animal manure. Another lives on decaying leather, the top of jam, damp stale bread, etc.

The plant body of *Mucor* is composed of long, branching threads or **hyphæ**, colourless in appearance. It reproduces itself in two distinct ways. One is sexual and the other is by the production of spores, very similar to the spores of bacteria. When *Mucor* is about to reproduce by spores, it sends off upright branches, about one-eighth of an inch long. The top of each branch swells into a small black sphere which develops hundreds of spores within it. Each branch therefore looks like a small pin, hence the common name, **pin mould**. The wall of each sphere eventually breaks and all the ripe spores are shed

into the atmosphere. They are exceedingly small and, like the spores of bacteria, are capable of withstanding adverse condi-

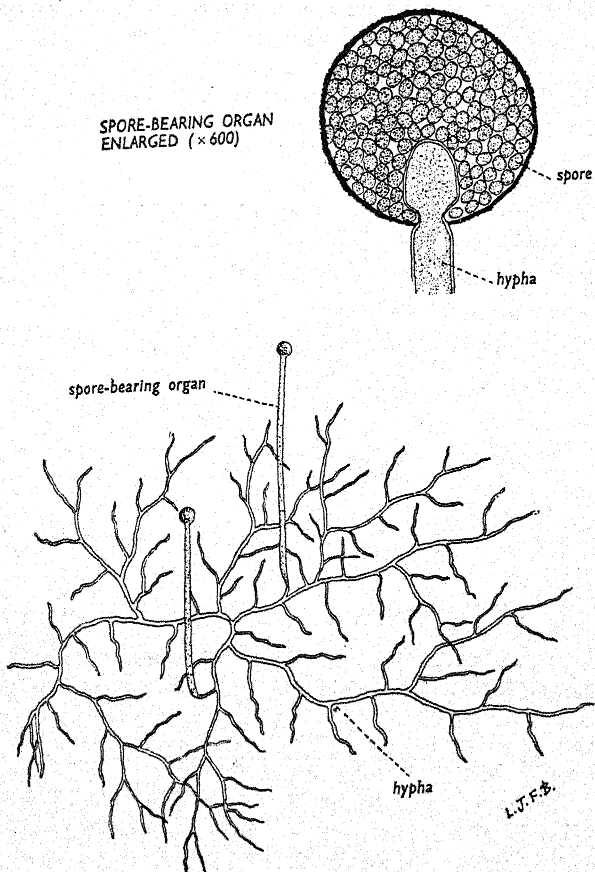


FIG. 195. *Mucor*, A SAPROPHYTIC FUNGUS.

tions. There are millions of such spores in the atmosphere. Of course, the majority die, since they cannot find a suitable place for growth. But, since they are so common in the atmosphere, it is no wonder that a suitable food such as exposed jam and damp

bread soon becomes mouldy by the growth of this saprophyte. (Fig. 195).

Another saprophytic fungus is used in the making of Gorgonzola cheesė, a brand of cheese made in England, but more famous in Italy. This fungus is called *Penicillium* (Fig. 196). It is inoculated into the cheese and there it develops by living saprophytically on the food-stuffs in the cheese, eventually

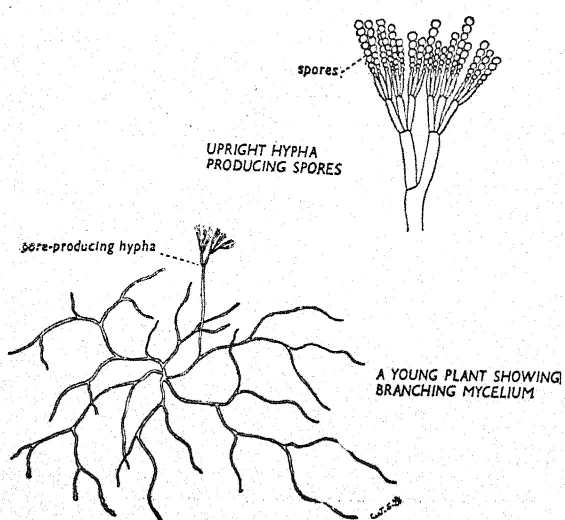


FIG. 196. *Penicillium,* A SAPROPHYTIC FUNGUS (HIGHLY MAGNIFIED).

producing the characteristic green veins in the cheese and an improvement in the flavour of it.

Much more familiar are the saprophytic fungi which grow in meadows and on the trunks of trees. Though they never contain chlorophyll, they are not always colourless, for many are brightly coloured, usually yellow or red. Familiar examples of such saprophytic fungi are the mushrooms and toadstools.

The familiar, umbrella-shaped portion of the mushroom is not the main part of the plant. It is the reproductive organ. The vegetative part of the plant is composed of very fine, colourless,

branching hyphæ which thread their way through the soil containing plenty of decaying humus, such as leaf-mould and animal manure (Fig. 197). In Nature, the mushroom reproduces itself by means of spores which are produced on the under surface of the well-known structure which grows above the soil. If the under surface of this structure be examined, it will be seen that there is a large number of surfaces radiating from the

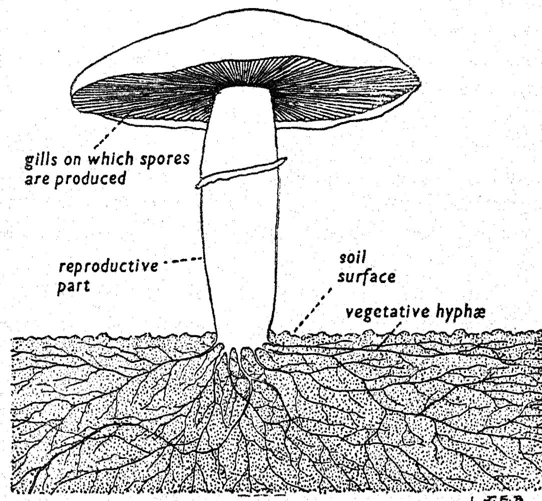


FIG. 197. THE MUSHROOM, A SAPROPHYTIC FUNGUS.
Note the vegetative hyphae growing below the soil, and the reproductive part growing above.

centre. These are called gills, and on these gills the spores are produced. The number of spores that one mushroom is capable of producing is nothing short of amazing. Professor A. H. R. Buller, a well-known Canadian specialist in fungi, has estimated that one large mushroom is capable of producing 10,000,000,000 spores. It stands to reason, therefore, that there must be great mortality amongst all plant spores, for if they all produced new plants, in a very short time the whole world might be smothered with mushrooms alone.

Plant spores of all kinds, being extremely light, travel at great

heights in the air. In 1932 an American botanist attempted to discover the maximum height at which spores can travel through the air. By means of an aeroplane, he collected plant spores 18,000 feet up. Probably they travel even higher. More recently, scouting aeroplanes have found the spores of disease-producing fungi 10,000 feet up in the air. Investigations carried out in the United States Department of Agriculture have shown that it takes such spores 55 hours to fall to earth again, even in a perfectly still atmosphere. So it is clear how tremendous are the areas over which plant disease can be spread, unless the spores are brought down by rain or some other agency.

The reproductive part of the mushroom is edible, and the plant is therefore cultivated for the purpose. The chief thing is to supply a soil very rich in humus, and a rather high temperature. Light is not necessary, and that is why mushrooms are usually cultivated, not in fields, but in disused barns, cellars and tunnels. It is very seldom that the spores are planted like seeds. More common is it to get blocks of soil in which it is known that there are plenty of the real mushroom hyphæ. These blocks are called **mushroom spawn.** The soil used is often covered with grass, so the turf is lifted and the spawn placed beneath. Nowadays, the soil is often electrically heated, since a rather high temperature is desirable. This is worth while, since cultivated mushrooms generally command a high price on the market.

In connexion with the wild varieties of saprophytic fungi closely allied to the mushroom, the so-called '**fairy rings**' of our fertile meadows are of interest. These rings are usually almost perfect circles of a darker green present in the grass of certain fields. They derived their name from the old-fashioned belief that they were caused by the fairies dancing round on the grass during the night.

Fairy rings are due to several types of fungus. One is the **fairy-ring mushroom or champignon.** This mushroom is more delicious than the common edible mushroom, and is used extensively in Italy and France for food. It grows in certain parts of Great Britain also, and is treasured as a great delicacy. But all fairy rings are not caused by this mushroom. Other fungi are

also responsible. The deeper colour of the grass is due to the presence of thousands of the fungal spores in the soil. If one spore be imagined to develop in the soil, it can easily be seen how the hyphæ from that spore will grow out in all directions from it, like the spokes of a wheel. Then new spores are formed, but only by the youngest parts of the hyphæ ; that is, the ends of the hyphæ, on the circumference of the circle. Hence the formation of the ring. The older parts of the hyphæ die away, and growth goes on year after year, always in an outwards direction. Thus the rings are getting larger and larger. Some fairy rings are estimated to be 300 to 400 years old.

It is well known how unhealthy decaying plant and animal material can be. Therefore, certain saprophytic plants, fungi and bacteria, are useful to man in absorbing such material. Some saprophytic fungi and bacteria are thus natural scavengers of rubbish.

On the other hand, certain saprophytic plants can be very harmful. All householders, builders and architects know of the so-called 'dry-rot' which often attacks structural timber, reducing it to a powder. This dry-rot does millions of pounds worth of damage every year. Dry-rot is caused by a saprophytic fungus, *Merulius lacrymans*, which, penetrating the elements of the wood, absorb nutrifying material and cause the wood elements to disintegrate. To prevent attack from this fungus the wood is often covered with creosote.

Semi-Parasites

There are certain other plants which actually live on plant hosts and extract a certain amount of food from their hosts. But they are not so objectionable as true parasites in that they do not *completely* depend upon their hosts for their manufactured food. They manufacture a great deal for themselves. Therefore, such plants must possess green leaves in order to do so. Since they extract only a certain amount of food from their hosts and make the rest for themselves, they are called **semi-parasites.**

A very well-known example of a semi-parasite is the **mistletoe** (*Viscum album*). This plant is an evergreen with forking

branches and opposite leaves. It produces yellowish flowers in February and March, and eventually its well-known white berries which contain a viscous, very sticky fluid. The plant lives on apple and, more rarely, hawthorn and oak trees as hosts (Figs. 198 and 199). The seeds get on to the branches of the hosts through the agency of birds. The birds pick the berries, and in their efforts to get the sticky material off their beaks, they rub

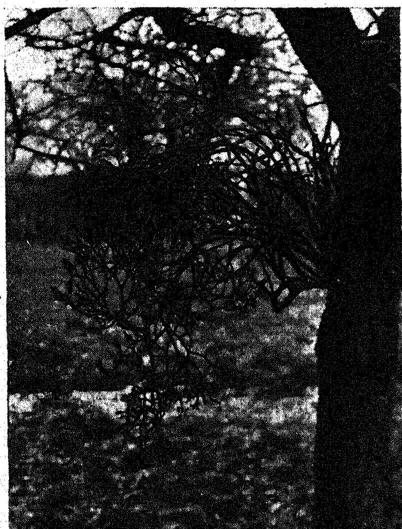


FIG. 198. MISTLETOE GROWING ON AN APPLE TREE.
(*Photo. Flatters and Garnet, Ltd.*)

their beaks on the branches of the trees. Thus the seeds are sown.

The seed germinates by sending off a sucker or haustorium into the bark of the host and thus penetrates the wood vessels. From the wood vessels of the host, it is clear that all the parasite can get is water and dissolved mineral salts. But this is all that it requires, for, having got this, it can carry on food manufacture itself through its own photosynthetic leaves. Thus the haustorium of the mistletoe in the branch of the host performs the functions of the root of a normal plant in the soil. The mistletoe,

so extensively used in Great Britain at Christmas, is obtained chiefly from the apple orchards of Normandy and Herefordshire.

Closely connected with irregular modes of nutrition is the phenomenon of symbiosis. In this case it is not a question of

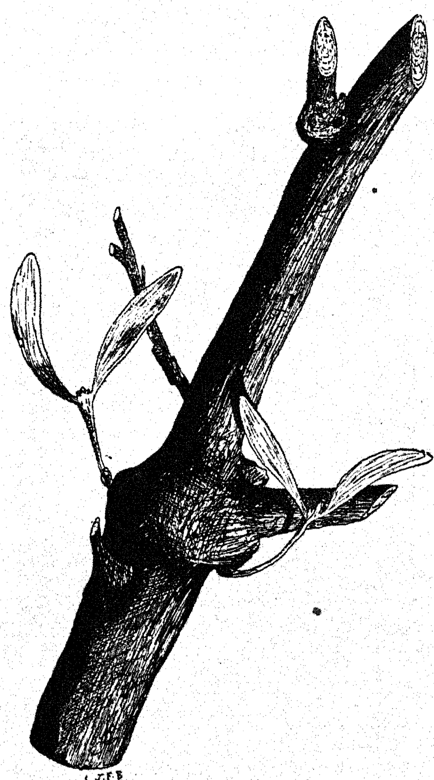


FIG. 199. YOUNG SEEDLINGS OF MISTLETOE DEVELOPING ON AN APPLE TWIG.

(Drawn from a specimen in the Museum, University of Manchester.)

parasite and host, but two plants living together for mutual benefit. Lichens are composed of a mixture of algæ and fungi. The fungus extracts food from the photosynthetic algæ, whereas the latter obtains a certain amount of protection from desiccation

and other adverse conditions by being enclosed in the hyphal threads of the fungus. Symbiosis between certain roots and nitrogen-fixing bacteria has already been described (Chap. VIII).

PRACTICAL WORK

1. Examine and draw the leaf of a potato plant stricken with potato blight. Look for the lighter patches (or if the disease is advanced they will appear dark brown), where the leaf is attacked by the fungus (*Phytophthora*).

Obtain a prepared microscope slide of a section of an infested leaf and look for and draw the hyphæ of *Phytophthora* ramifying through the tissues of the leaf.

2. During the summer, look for plants of dodder coiling around the stems of clover, heather, gorse, nettles, etc. Gather some specimens for detailed study.

Make a drawing of the whole plant, noting the manner in which it coils around its host, its reduced, scale-like leaves, and its pink flowers. Notice the absence of chlorophyll, and explain the parasite's method of nutrition in view of this.

Make a thorough examination of the haustoria and cut a transverse section of the stem of the host plant, in the region of a haustorium. Notice the type of host tissue which the haustorial cells penetrate. Make drawings of the section.

3. Make drawings of, and describe, any other parasitic or saprophytic flowering plants which may be identified during a country excursion.

4. Place some damp bread under a bell-jar and leave it for a few days until it becomes 'mouldy.'

Then take a very small portion of the mouldy bread and examine the fungus responsible for this condition, with the high power of the microscope. Look for, draw and describe any spore-producing bodies of *Mucor* which may be discovered.

5. Examine, draw and describe the reproductive portion (fructification) of a mushroom.

Choose a ripe fructification and remove the **stipe** ('stem') and place the umbrella-shaped part (**pileus**) on a piece of paper with the gills downwards. Leave for a few days, then gently lift the pileus, when the shape of the gills will be traced on the paper by thousands of small, black, reproductive spores which have been shed.

6. Examine a mistletoe plant (if possible still growing on its host). Notice the green leaves, and thus explain why this plant is referred to only as a semi-parasite.

CHAPTER XV

PLANTS WHICH PREY ON LIVING ANIMALS

Although plants are consumed whole or in part by animals, there are very few cases where plants actually consume animals. Normally they only consume the very much changed products of animals.

Nevertheless, there are examples of plants preying on living animals for the purpose of nutrition. They actually catch the animals, kill them, and then digest them. But such examples are rare, though they have not suffered from the want of extravagant advertisement.

Animal-eating plants have caught the imagination of many a person, and are especially common in stories of travellers of days gone by. For example, for many years travellers in the unknown parts of certain tropical regions used to come home with awe-inspiring yarns of a 'man-eating tree,' that is, a tree which was able to trap a man if he got too near it, and then digest him. Though this myth held sway for a long time, no such tree exists. In fact, very few animal-digesting plants exist, and those which do are content with insects and other very small animals. None of them are sufficiently powerful to trap and kill very large animals.

Insectivorous Plants

Some plants, since they consume insects, are called **insectivorous plants**. Although comparatively rare, they are of extreme interest in that they have all developed most wonderful methods for catching their insect prey. Also, they are worthy of a little consideration, for even these animal-eating plants have been the subject of gross imagination and exaggeration, even in modern textbooks.

Charles Darwin

Much work on the insectivorous plants was done, chiefly by the best method, that of field observation, by one of the greatest naturalists the world has ever known, of whom more will be said later on (Chap. XXIV). This great scientific worker was **Charles Darwin** (Fig. 76).

Charles Darwin was born in 1809 at Shrewsbury. He was a very successful worker in various scientific fields, with the result that he revolutionised existing ideas in many branches of science, and brought new light to bear on the great question of why there are so many different forms of plants and animals (Chap. XXIV).

The way in which Darwin achieved such success might well be taken to heart by all those who wish to make any scientific study a success. This way is best described in his own words : " The love of science, unbounded patience in long reflecting over any subject, industry in observing and collecting facts, and a fair share of invention as well as common sense."

From December 1831 until October 1836, a ship named H.M.S. *Beagle* was sent out on a scientific surveying expedition, going to several Atlantic islands, the South American coasts, Tahiti, New Zealand, Australia, Tasmania, Mauritius, St. Helena, and Brazil, amongst other places. Much to his delight, Darwin went on this famous expedition as its naturalist. It was on this expedition that Darwin collected many of his facts on which he based his epoch-making theories later on. So important were some of his publications that his book on insectivorous plants, which was published in 1875, was only of a comparatively minor character. Nevertheless, this publication paved the way to still further study of these plants, thus giving us much of the information we have to-day concerning them.

Before considering any examples of insectivorous plants, it is necessary to reflect on them in general, chiefly to get rid of any exaggerated ideas that we may have of them. Some of them may be found in Great Britain. It is quite true that they trap insects, and consume certain digestible parts of the body of their victims. But not one insectivorous plant depends *completely* on insects for its nutrition. It is possible to go even further than

that: *insects never form more than a very small fraction of the diet of insectivorous plants.* There is no need to watch such a plant and see how many insects it catches in a certain length of time to learn this, for, when it is realised that all insectivorous plants possess their normal quota of green leaves, it can be concluded immediately that their main source of food supply is the normal one, that is, photosynthesis.

Since this is the case, the question arises: Why do such plants go to the trouble of trapping insects at all? This, too, is easily answered. Most insectivorous plants frequent swampy and boggy localities. In such localities there is a very sparse plant and animal population. The result is that the almost water-logged soil contains comparatively little humus. Consequently, the nitrogen content of the soil is very low. Also the nitrates that are present are being quickly leached out of the soil by the abnormal amount of water present. Therefore, plants which grow in such localities or habitats tend to suffer from the want of nitrogen, which they require for food, especially protein, manufacture. Now insects and other small animals which these plants trap have a high protein content in their bodies. Thus, by digesting them, insectivorous plants obtain an extra supply of nitrogen, to make up for the deficiency of that element in such soils. Therefore, the insectivorous habit is a means, not of supplying a great amount of food, but merely of making up a deficiency in raw food material, especially nitrogen.

Though insectivorous plants actually can do without such animal food, there is little doubt that the nutrition obtained by them is valuable. This can be realised best from the words of **Julius von Sachs**, the great German botanist, who replied, when someone pointed out that insects were not absolutely necessary to these plants: "In Poland and Ireland a great many people live only on potatoes, but it does not follow that a beef-steak wouldn't be a good deal better."

Insectivorous Plants of Temperate Countries

A few species of plants of insectivorous habit are to be found growing wild in Great Britain.

One rather common insectivorous plant is the **butterwort**

(*Pinguicula vulgaris*). This is a herb, with leaves 1 to 3 inches long, arranged in rosette fashion (Fig. 200). The upper surface of the leaves is covered with a pale yellow, sticky substance which looks like a thin layer of butter; hence the name. An unwary insect alighting on this sticky surface gets caught like a fly on a fly-paper. The margins of the leaf are slightly incurved (Fig. 200), and, when an insect is caught, they curve over still further, thus gripping the insect.

On the surface of the leaves are certain microscopic structures called **glands**. These glands give off a juice containing enzymes which help the splitting up of the proteins of the insect body, thus making them digestible. The digested proteins are then absorbed by the surface of the leaf. This plant is quite common in Great Britain, especially on the Somersetshire Plain, and in Yorkshire and Scotland. It is very widely distributed in the north temperate zone, and is common in certain parts of Canada and the United States.

FIG. 200. BUTTERWORT.
(*Photo. Henry Irving.*)

Another British insectivorous plant, but one with a more complicated trapping mechanism, is the **sundew** (*Drosera rotundifolia* and *Drosera longifolia*). The leaves again supply the trapping mechanism. They are green with patches of red on them and possess long petioles. The laminæ are round or oval according to the species. The leaves are again arranged in rosette fashion. The flowers are white and are arranged on rather long, upright inflorescences (Fig. 201).

The edges and upper surface of the leaf of the sundew are covered with long, hair-like outgrowths called **tentacles**. There are about 200 tentacles on one lamina. Each tentacle ends in a

club-shaped swelling covered with a sticky substance which looks like dew; hence the name. When the insect alights on the leaf, it is thus caught by the sticky tentacles. Then there is a general bending of all the tentacles towards the mid-rib, with the result that the insect is caught and pressed firmly against the leaf surface by the tentacles (Fig. 202). The ends of the tentacles then secrete a protein-digesting enzyme, and thus the insect is digested and absorbed. After the process is finished, the leaf attains its normal form again, and the indigestible parts of the insect are exposed and blown away by the wind.

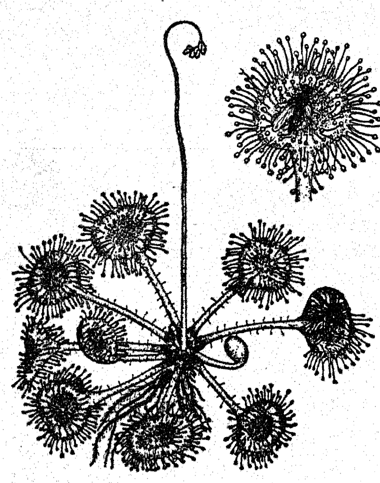


FIG. 201. *Drosera rotundifolia* (NATURAL SIZE).
Above, a leaf (× 2).
(*After Errera and Laurent.*)

The two species mentioned of the sundew are common in the swampy regions of Great Britain. This plant is also common in North America, and very common in Australia.

A closely related insectivorous plant called *Drosophyllum* is common in Portugal and it catches so many flies that the peasants of that country call it the 'fly-catcher,' and hang it up in their houses for that purpose just as fly-papers are suspended in fly-infested rooms in this country.

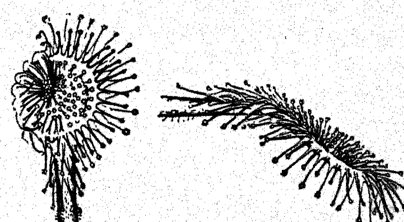


FIG. 202. Leaves of *Drosera rotundifolia*.
Left, viewed from above; right, viewed from the side. The leaf on the left has been touched by a pencil (resembling the alighting of an insect) and the tentacles have bent inwards.

(*After Darwin.*)

An even more ingenious method for trapping small animals is shown in another well-known insectivorous plant which grows in certain parts of Great Britain, called the **bladderwort** (*Utricularia vulgaris*). This is a water plant, and it lives chiefly in stagnant water where tiny animals abound.

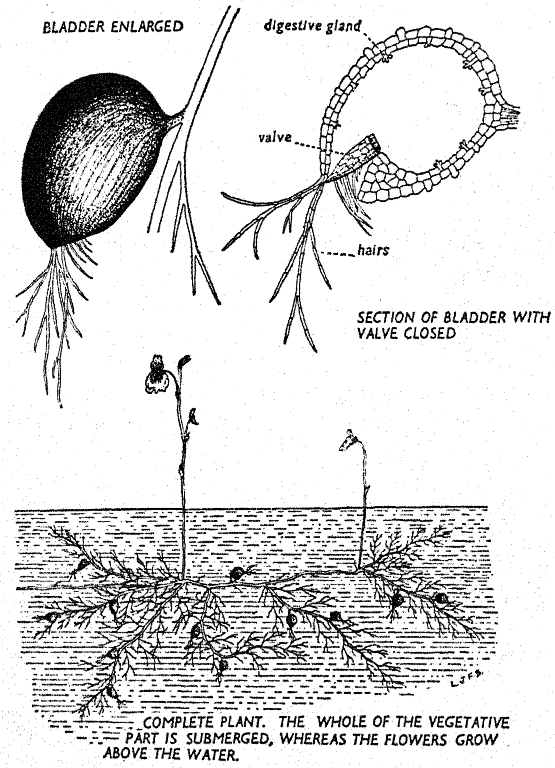


FIG 203. BLADDERWORT.

The leaves of the bladderwort are very finely divided, as is the case in many examples of completely submerged leaves. This is to allow the water to flow past the leaves without breaking them, as it certainly would do if the leaves offered a large, unsegmented surface. Certain of these leaf segments become much

modified into bladder-like structures, thus giving the plant its familiar name (Fig. 203). Each bladder has one opening which is protected by a valve.

The valve is as efficient as any valve contrived by an experienced mechanic, for, while it will open inwards, it will not open outwards. A small, unwary insect can thus pass into the bladder by pushing the valve aside. It probably uses these bladders as a form of sanctuary from pursuing enemies. But, unfortunately for the insect, once it has got inside it cannot get out again, for the valve will not open outwards. The inside surface of the bladder is covered with glands like those of the butterwort, which secrete protein-digesting enzymes (Fig. 203). These digest the proteins of the insect, and then the soluble nitrogenous matter is absorbed through the surface of the bladder. The bladderwort is rather common in Great Britain and in other parts of the north temperate zone.

Insectivorous Plants of the Tropics

The three insectivorous plants just described are the only ones which grow wild in Great Britain. This shows how comparatively rare insectivorous plants are. But there are a few very interesting plants which demonstrate this habit, native to tropical and subtropical regions.

One such plant is called **Venus's fly-trap** (*Dionœa muscipula*). This plant is very common in the peat bogs of North and South Carolina (Fig. 204). The first full description of the insectivorous habit of this plant was given by Charles Darwin, though it had actually been noticed before.

The insectivorous habit is again connected with the leaf, and the mechanism is truly wonderful. The leaves are arranged in rosette fashion, as in British terrestrial insectivorous plants.

Each leaf has two lobes on either side of the mid-rib. On the margins of each lobe are long, firm spikes (Fig. 205). The surface is covered with glands, and each lobe has three bristles, each of which is sensitive to touch. When an insect alights on the surface it cannot help but touch one or all of these sensitive bristles. The result is that in less than a second the lobes move towards each other, using the mid-rib as a hinge.

The margins of the lobes meet each other, and the strong spikes intertwine with each other and prevent the lobes from being pushed apart. Thus the insect is trapped in a way very similar to the catching of a rat with a gin. Then the leaf acts like a

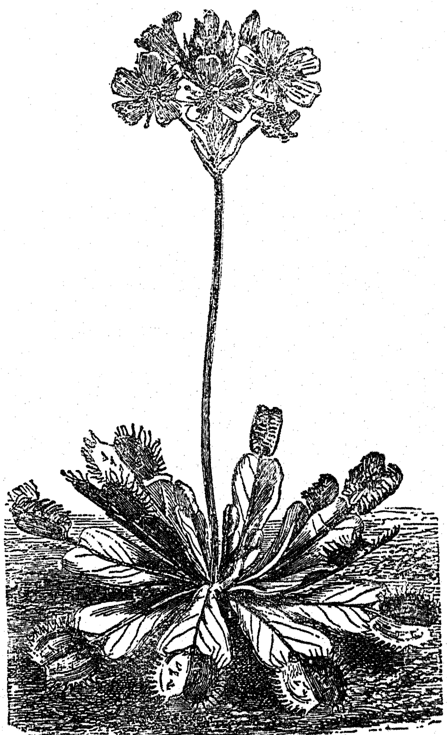


FIG. 204. VENUS'S FLY-TRAP, SHOWING SOME OF THE LEAF BLADES OPENED AND OTHERS CLOSED.

digestive gut, and the proteins of the captured insect are absorbed and supply extra nitrogen to the plant.

It is interesting to note the instructive observation that Darwin made on this trapping mechanism. His experiment showed what a great deal of juice containing the protein-digesting enzymes is secreted by the glands of this fascinating leaf. He

waited until an insect was caught in a trap, then immediately made a small perforation at the base of the lobes, without removing the crushed insect. The digestive fluid poured out of this hole and flowed down the leaf-stalk, and it continued to do this for nine days.

The most interesting type of insectivorous plant is represented by the so-called **pitcher plants**, native to tropical and

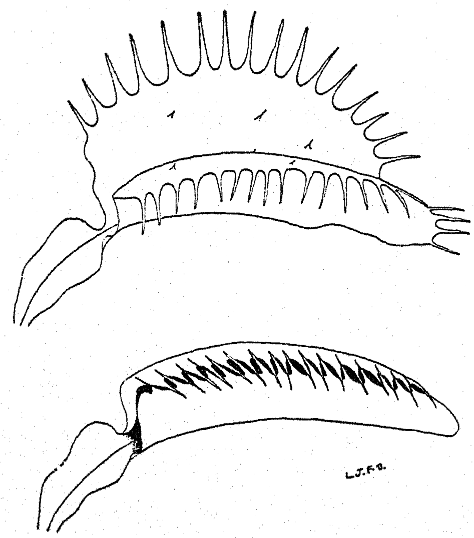


FIG. 205. LEAVES OF VENUS'S FLY-TRAP.
Above, leaf opened, showing spiked margins; below, leaf closed, showing interlocking of spikes.

subtropical regions. There are several types of plant which have this pitcher habit. They are grouped together here because they all have the same insectivorous habit. This takes the form of a pitcher-shaped structure in which the insect prey are trapped.

Pitcher plants are native to tropical Asia, north Australia and Madagascar. North Borneo is especially rich in them (Fig. 206).

The true pitcher plants are called *Nepenthes*, and there are about 60 different species of them. The majority are shrubby plants, climbing by means of tendrils which are really extensions of the mid-rib of the leaves, from the leaf tips. Certain of the leaves appear to develop a pitcher at the end of the lamina. Actually, this is not the case. As was shown by **Professor Karl von Goebel**, the famous German botanist, the actual pitcher is the modified lamina, and, since something else must take the place of this very modified lamina in order to carry on photosynthesis, the leaf petiole becomes flattened. Thus, what appears to be the leaf lamina is really the leaf petiole. So here we have the petiole modified into a laminar structure for photosynthetic purposes, and the lamina modified to form a pitcher for insectivorous purposes (Fig. 207).

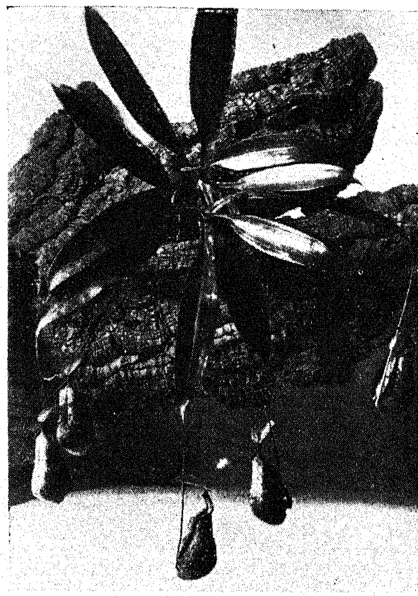


FIG. 206. A PITCHER PLANT.
(*Photo. A. H. Bastin.*)

The pitcher itself is a tubular structure, often bearing two wing-like structures running down its outer surface. The rim of the mouth has an incurved margin, which has a firm, shining surface. The mouth has a definite lid, just like that of a coffee pot or hot-water jug. When the pitcher is very young, the lid covers the opening; but as the pitcher grows, the lid opens and is then stationary. It takes up an oblique position, and is probably used for keeping rain-water out of the pitcher.

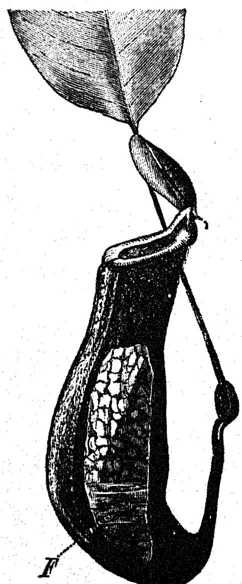


Fig. 207. A Pitchered Leaf of *Nepenthes*.

A portion of the wall has been removed in order to show the digestive fluid (F) ($\frac{1}{2}$ natural size).

(*After Noll.*)

The size of the pitcher varies with the species, from the size of a thimble to that of a quart mug. The outside of the pitcher is often brightly coloured. The colours vary from shades of red to yellow, etc., and the variation depends on all sorts of factors, such as light intensity and soil conditions. These bright colours, like the bright colours of flowers, serve to attract the insect prey. A sweet substance is also secreted by the stems of the plant and right up the petiole to the lid of the pitcher. Still more sweet material is given off inside the pitcher, just below the margin.

The insect is first attracted by the bright colours. Then in its attempt to get the sweet food material it crawls up to the margin of the pitcher, and tries to get at that just inside. In doing so, it often slips on the shining surface of the rim and tumbles into the pitcher. Once inside it is trapped, for two reasons. The inner surface of the pitcher is covered with glands. These glands secrete a watery substance which collects in the bottom of the pitcher (Fig. 207). Into this liquid the insect tumbles and is thus disabled. Also, on the inner surface, near the top of the pitcher, is a ring of hairs

which point downwards. It is easy to see, therefore, how the insect can fall over these hairs, but, even if it can attempt to climb out, the downward direction of the hairs prevent it. It would be like trying to get through a barbed-wire entanglément. Thus the insect gets fatigued, falls into the liquid, and is finally drowned. Then the same glands secrete a protein-digesting enzyme, and the insect body is thus digested and finally absorbed.

This is a fascinating mechanism and seems to be very efficient as a means of trapping insects. But, in Nature, the pitcher plant is not so efficient as one would imagine. Although insects are trapped in this fashion, botanists who have studied pitcher plants in their native localities tell us that they are sometimes so inefficient that they do not work at all. This happens to such an extent that mosquitoes have been known to enter the pitchers, lay their eggs, and the young have been hatched out and escape. The pitcher, therefore, is not only an insect trap but also, at times, it is so inefficient in its function that it becomes a breeding ground for insects.

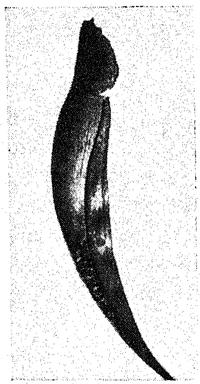


FIG. 208. PITCHER OF *Sarracenia*. (*Photo. A. H. Bastin.*)

Other types of pitcher plants belong to the type known as *Sarracenia*. These are all native to the eastern regions of the United States, and there are about seven species of them. They are all herbs. The leaves grow direct from the soil, and some of them form pitchers (Fig. 208). In this case, the leaf is different from that of *Nepenthes* in that, except for a broad sheathing base, the whole leaf forms a long, tubular pitcher, with a lid at the mouth. These pitchers are similar to those of *Nepenthes* in their mechanism for trapping insects. They are, however, probably more efficient. Sometimes, in fact, the pitcher is almost full of insects. Thus, when the *Sarracenia* plant dies, it supplies a considerable amount of manure to the soil in the form of dead insect humus.

Also it has been known that *Sarracenia* is a means of catching insect prey for other animals. The pitcher is often so efficient that it catches many more insects than it can possibly absorb and, as it becomes nearly full of them, other insect-eating animals, such as larger insects and even birds, come along and help themselves to the prey. Insects have been known to enter the pitchers of *Sarracenia* and lay their eggs. The eggs hatch and then birds have been seen to slit open the pitchers with their beaks and feast on the insect larvæ inside.

It will be noticed that the insect-trapping mechanism of all insectivorous plants, both British and foreign, are produced by the laminæ of the leaves. In some cases, such as the butterwort, they are scarcely modified at all, whereas in others, such as *Nepenthes*, they are modified to form an organ completely different from the normal laminar structure.

Pitcher plants, chiefly for the bright colours of their pitchers, are sometimes cultivated in greenhouses in Great Britain. They may be seen, too, in the greenhouses of many public botanical gardens. Those in the Royal Botanic Gardens at Kew, Surrey, are excellent specimens, and well repay a visit.

PRACTICAL AND FIELD WORK

British insectivorous plants are studied best in their native habitats.

Butterwort and sundew are to be found on the acid soils of moors, where there is a lack of nitrogenous compounds. Both are usually found in the wetter parts of moors, and sundew may be found even in boggy soils.

Both plants can be kept in a room for some considerable time, provided there is plenty of the original soil left around the roots. This should be kept damp.

The commonest British butterwort (*Pinguicula vulgaris*) has rosette leaves. These should be examined and a specimen drawn, to show the incurved margins. Note the sticky nature of the upper surface. Another species, *Pinguicula lusitanica*, is fairly common near the shores of the west of England.

The commonest British sundew is *Drosera rotundifolia*, which may be found in bogs. It has creeping rhizomes. Note the rosette arrangement of the leaves. This species has fairly short petioles. Draw a leaf, noting especially the tentacles. Lightly touch the leaf with a pencil and try and get the tentacles to respond as if they

are trying to trap an insect. This experiment is usually more successful in the field, rather than on a disturbed plant.

The commonest bladderwort (*Utricularia vulgaris*) is to be found in ditches and pools of brackish water. Obtain a specimen and make drawings of it. There are no roots to this plant. The leaves are very finely divided. The flowers project above the water. Note especially the shape of the bladder, and the presence of hairs at the orifice. Open several bladders and look for the remains of animal prey (chiefly Crustacea).

The tropical examples of insectivorous plants are not so easily available, of course. However, specimens of *Nepenthes* and *Sarracenia* are usually to be seen in the greenhouses of botanic gardens. When visiting such gardens take the opportunity of examining any specimens there and, if possible, make drawings, especially of the pitchers, noting and explaining their modified nature.

CHAPTER XVI

MANUFACTURE OF OTHER PLANT MATERIALS

APART from essential food materials, constituents of protoplasm, chlorophyll pigments, and other substances, the manufacture of which have already been considered, there are many other chemical substances manufactured by plants. Though they are not so essential, they are usually of great importance to those plants concerned. Some of them are useful to man in various economic ways, whereas others are not. None of them are common to all plants, but are peculiar either to one special plant or to a group of plants. Of course, it would be quite impossible to consider them all; but to study a representative few of them would well repay the effort.

Colour of Flowers

Few people can fail to be deeply impressed by the remarkable display of colour that plants often show. Many are familiar to us in the delightful hues of flowers, which often present wonderful splashes of colour either in the wild state, or under cultivation, or as forms of decoration in the home. In the petals of flowers, almost every conceivable shade of colour is represented.

Before proceeding to consider any of these, it will be interesting to examine those flowers, such as the snowdrop, many lilies, narcissi, etc., which are not coloured. The whiteness of some flowers is so pure as to be almost dazzling. Yet, this is not due to any white chemical pigment present in the cells of the petals.

All the cells of the petals of white flowers are colourless and transparent. Therefore, on casual consideration, petals instead of being white should be transparent and colourless like a sheet of glass. But the petal is not one continuous sheet of material. It is composed of hundreds of small, colourless cells. If a sheet

of glass be laid flat it naturally appears transparent. If, however, the sheet be crushed into a fine powder, the resulting layer of powdered glass would no longer be transparent, neither would it be colourless. It would be white. This is due to the irregular reflection or scattering of light; and it is this light scattering by the hundreds of cells of the colourless petal that makes the petal actually appear white.

The colours of petals, on the other hand, are caused by different coloured chemical pigments. Sometimes only one pigment is present and then, of course, the colour of the flower is that of the pigment present. More often, however, several differently coloured pigments are present, and then the shade of colour produced in the flower is the result of the mixing of the colours.

The chemical nature of many flower pigments is fairly well understood to-day, though there is still a great deal to find out. Most of the pigments can be classified into two groups, the **anthoxanthins** and the **anthocyanins.**

Anthoxanthins

Anthoxanthins are all yellow pigments, and they are responsible for many yellow colours in flowers, and also certain vegetative organs of plants. Wherever these yellow chemical substances are present, they differ from chlorophyll in that this latter pigment is present in the granules called chloroplasts, which are embedded in the cytoplasm. The anthoxanthins, on the other hand, are soluble substances and are dissolved in the cell-sap. Thus, in the yellow cells, the vacuoles are filled with a yellow solution.

In the case of white flowers, sometimes certain yellow anthoxanthins are present in the cell-sap of the cells, though in such small quantities that they give no visible colour to the petals. Their presence, however, can easily be detected for this reason: many anthoxanthins turn a deeper yellow or even green when exposed to ammonia vapour. Therefore, if certain white flowers be placed in ammonia vapour, they often turn a yellow or green colour. This chemical process is made use of in the production of artificial green flowers, such as green tulips and carnations.

Pure yellow flowers, such as daffodils and buttercups, owe their colour to the presence of yellow anthoxanthins and carotene (one of the yellow pigments present in chlorophyll) dissolved in the cell-sap. The colouring matter can be extracted by placing the dried petals in boiling alcohol, when the anthoxanthins and the carotene will dissolve in the alcohol.

Anthocyanins

Of much more common occurrence are the anthocyanin pigments. These occur in many chemical forms and colours. In their pure state, and in various combinations with each other, they are responsible for many of the beautiful shades of colour present in flowers, and other plant organs.

Anthocyanins are responsible chiefly for the blue, red, purple and brown shades so familiar in Nature. There are many of them ; therefore it is impossible to consider all separately. A few are, however, worthy of mention. For example, **pelargonin** is the anthocyanin responsible for the bright red colour of the petals of *Pelargonium* and *Geranium*, **delphinin** for the beautiful blue of delphiniums and monkshoods, **cyanin** for the striking cornflower blue, **œnin** for the blue-black of grape skins, etc.

Such colouring matters are soluble in glacial acetic acid. If, therefore, some grape skins or geranium petals be soaked in this, the anthocyanins are dissolved out.

Many anthocyanins are capable of changing their colour. At one time it was considered that they change their colour according to the acidity or alkalinity of the cell-sap. A familiar indicator in the chemistry laboratory is litmus. When this is added to an acid it goes pink ; on the other hand, in an alkali it goes blue. Many anthocyanins were therefore considered to be indicators, thus giving striking changes in the colour of flowers, sometimes even the same flower. For example, a change in the colour of the anthocyanin is seen in the forget-me-not. This flower normally is a beautiful blue colour, owing to the presence of an anthocyanin. When forget-me-nots have been kept in water for some days they begin to die, and the natural blue colour turns to pink. This is seen in the same flower even in Nature. Normally it is blue, but very often it is pink. Blue

delphiniums, too, often turn pink when they are beginning to wither. What causes this change of colour is not clear, though it is known that it is not always due to the acidity or alkalinity of the sap.

In spite of this, however, a change in the acidity often does cause a change in colour. This can be seen more clearly by taking some blue flowers such as delphiniums or forget-me-nots and immersing them in a very weak acid, such as vinegar. They will then turn pink. This also underlies the habit of some children, especially in Yorkshire. They take bluebells and place them in ant-hills, which turn them pink. Ants produce an acid called formic acid, which is responsible for the painful sting of these insects. The change of the blue colour to pink in the bluebells is therefore probably due to the formic acid changing the cell-sap of the petals from an alkaline to an acid state.

The significance of the colouring matters of flowers has not been settled yet. Some botanists say they are used in respiration. One thing is practically certain. As will be seen later, many flowers depend upon insects, especially bees, wasps and butterflies, for the process of fruit and seed production. The bright colours of the flowers possibly serve in attracting the insects, for those flowers which depend mostly upon insects are usually the most highly coloured.

The bright blues and reds in flowers are, as has already been seen, usually due to the presence of one special anthocyanin. But there are many other mixtures of shades, for example, brown wallflowers. The colouring matter here is a mixture of anthocyanins, carotene and anthoxanthins. Purple flowers are usually due to the presence of one anthocyanin only in neutral cell-sap, that is, cell-sap which is neither acid nor alkaline. The red colour of the beetroot is due to an anthocyanin. The copper colour of the leaves of the copper-beech is interesting. This is due to a combination of a red anthocyanin dissolved in the cell-sap of the leaf cells and the green colour of the chloroplasts.

In the olden days, many anthocyanins were used as dyes, especially for cotton fabrics. Many, unfortunately, are not fast colours, and they have therefore been supplanted by the more satisfactory fast, synthetic dyes which nowadays are

produced chemically, for example, as by-products in the coal-gas industry.

In the autumn coloration of leaves, the yellows are due to carotene and xanthophyll and the reds and purples to anthocyanins. Chlorophyll is always being formed, and always being destroyed, in a normal green leaf. During autumn, destruction goes on faster than formation. Hence, chlorophyll disappears, but the carotene and xanthophyll remain and anthocyanins are manufactured, chiefly from any foods left in the leaf.

Glycosides

Very widely distributed amongst plants is another group of chemical substances called **glycosides**. The majority of these are colourless, but all of them are manufactured by the plant, from raw materials. Nearly all of them are formed by the chemical combination of glucose or another simple sugar with another compound, a non-sugar.

When extracted and then dissolved in water, they all produce a very bitter solution. This may form a clue to the reason why plants manufacture them ; for they are apparently not absolutely essential to plants, and therefore many plants do not contain them. The reason why they are present in certain plants only is therefore a problem. The problem is made even more difficult when we realise that one plant contains one certain glycoside, whereas another plant contains a totally different one.

For example, in the sap of many coniferous trees there is a glycoside called **coniferin**. On the other hand, in the seed of the bitter almond there is one called **amygdalin**. Both are very different in chemical nature. Now, these two different glycosides are similar in one respect and that is, they are both extremely bitter. That is why such almonds are not suitable for eating raw as the sweet almonds are. Most probably, the bitter taste of coniferin also explains why animals do not eat the foliage of firs. So, in this case, it may be said that the two glycosides have the same function, that is, a form of protection against animals. On the other hand, there are certain glycosides present in the bark of different trees, in cell-sap and in leaves. Protective

functions in such cases are groundless, for many of them are tasteless. It has been suggested in such cases that they form a kind of food reserve for the plant, since they contain the carbohydrate glucose or another simple sugar.

Cyanogenetic Glycosides

Some glycosides, besides containing glucose and other chemical substances, also contain hydrocyanic or prussic acid, which is a deadly poison. In most cases, the amount of acid present is not enough to cause the death of an animal, but in some cases the amount of such glycosides (usually called **cyanogenetic glycosides**) is actually sufficient to cause death. For example, the leaves of the yew (*Taxus baccata*) contain a cyanogenetic glycoside in sufficient quantity to poison an animal, and even to cause its death if it eats sufficient of the foliage. This very often happens, and that is why domestic farm animals should be kept away from yew trees and hedges, especially in winter, when edible green foliage is scarce.

Certain plant glycosides are of use to man, but their use is not of any great importance. However, they are of interest.

One is of great historical interest. This is the glycoside called **indican**, which is present in several plants ; and a closely related glycoside is that present in the **woad plant**. From this glycoside, the very important textile dye, **indigo**, used to be manufactured. At that time, of course, the woad plant used to form a very important crop. Nowadays, its cultivation for the production of the glycoside for indigo manufacture is almost a thing of the past, for the indigo dye is now manufactured almost exclusively by chemical means. However, even to-day, in certain parts of Lincolnshire the woad plant is cultivated for the manufacture of indigo. Actually woad is a wild plant, growing in fields, on banks and especially around chalk pits. It is interesting to note that this was one of the plants used by the Ancient Britons for staining their bodies.

Saponins form another group of glycosides. These are present in quite a large number of different plants. They are noted for their highly poisonous properties in that they have the effect of dissolving the blood corpuscles. One part of saponin in

100,000 parts of water forms a solution sufficiently strong to kill fish. In the Far East this property is made use of for catching fish. The saponin solution is placed in lakes and ponds, and the fish when killed rise to the surface and float. They are then collected by the fishermen. There is no danger in this practice, since such a low concentration of the glycoside has no evil effects on the person who eats the fish. The juices from other plants have been used as fish poisons throughout the ages. For example, Pliny, the Roman author, who lived 1900 years ago, wrote of the Arabs using *Cyclamen* for the purpose. Even to-day, this plant, *Styrax* and mullein are used in the Near East. Saponins too, when mixed with other materials, are used for medicinal purposes, especially in cases of chronic bronchitis.

Several saponins, especially the one present in the **soap nut,** a plant growing in the Far East, are often used as substitutes for soap. They are valuable in this respect since they have no harmful effect on dyes or the most delicate fibre.

Solutions of saponins in water have the property of absorbing and retaining large quantities of dissolved gases such as carbon dioxide. For this reason, small quantities of them are often used in the manufacture of ginger beer and lemonade. The practice should not be encouraged, however, owing to the toxic properties of the saponins.

Tannins

Tannins form another group of chemical substances which are manufactured by plants and distributed very widely throughout the plant kingdom. They are not of very great botanical importance, but they are important from man's point of view since the tannins are used in several industries.

Tannins are all of an acid nature. The most important tannin is called simply **tannic acid.** Although tannins are distributed in all types of plants and in all plant organs, such as stems, roots and leaves, they are most commonly found in two plant structures. One is the bark of certain trees ; the other is what is called the plant **gall.**

A gall is a certain form of disease, and is usually caused by a parasitic insect, worm or fungus. The parasite penetrates the

tissue of the plant and then the cells of the plant around the parasite begin to divide very actively, thus causing a large swelling of tissue forming the gall. Several galls are familiar to the majority of people living in the country. One, for example, often develops on the leaves of the willow, and assumes

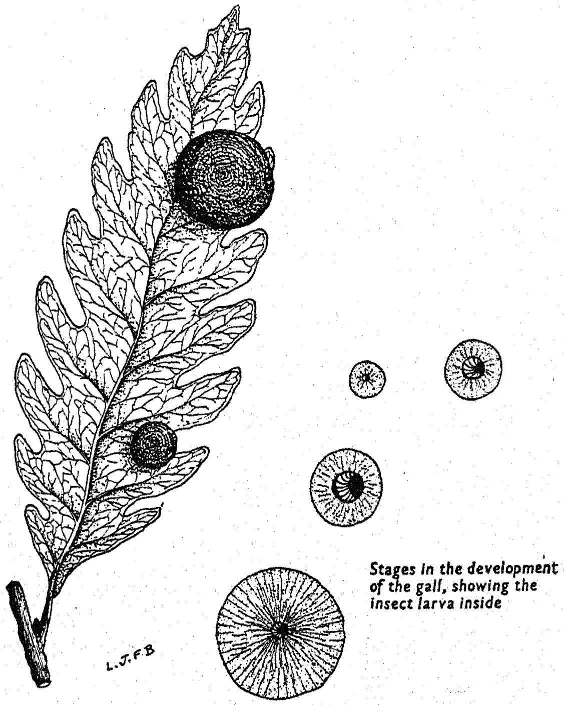


FIG. 209. 'OAK-APPLES,' GALLS CAUSED BY AN INSECT WHICH ATTACKS THE OAK.

the form of large red swellings. The well-known '*oak-apples*' are also plant galls caused by an insect (Fig. 209). The so-called '*witches' brooms*' which take the form of closely-packed branches on birch, elm, and fir trees, among others, are also a form of gall, in some cases caused by an insect parasite, and in others by a

fungal parasite (Fig. 210). Not all galls contain tannins, but many do, especially the oak-apple gall.

Tannins produced by galls are extracted and used in the manufacture of various **inks**. Ordinary black ink is made from gall tannins. The tannin is extracted and mixed with certain iron salts to produce the necessary colour.

FIG. 210. A TYPICAL 'WITCHES' BROOM,' CAUSED BY A FUNGAL PARASITE ON A BRANCH OF FIR.
(*After Kerner.*)

Certain other tannins were at one time used extensively in calico-printing and in dyeing fabrics; but now the chemical manufacture of dyes has become such an extensive industry, involving more efficient methods and giving much more satisfactory results, the use of tannins in this respect is fast dying out.

Leather

The greatest use of tannins, however, is in the manufacture of leather. The fundamental process in leather-making is the tanning of animal hides, which in many cases is done by means of plant tannins. The tanning of hides to make leather is one of the oldest industries. It probably was known to prehistoric man; it certainly was to the ancient Chinese, Egyptians and Romans. On the other hand, certain other familiar leathers are tanned in a totally different way. For example, glacé kid and box-calf are produced by treating the hides with chromic acid and sulphur, instead of plant tannins.

Many plant tannins are used for medical purposes. Certain drugs and ointments are prepared from them. For example, one is used for stopping intestinal bleeding. It is also used in the treatment of ulcers. In some cases the use of tannic acid has proved so valuable in the treatment of severe scalds and burns that the lives of many people have been saved by it. The application of tannic acid in the case of severe injuries from scalds and burns is still being closely studied by medical men in different parts of the world.

CHAPTER XVII

SPECIAL USES OF PLANTS TO MAN

APART from their fundamental value as foods, plants have been used for many other purposes from time immemorial.

The hundreds of thousands of different species of plants throughout the world vary considerably among themselves, both in structure and in composition. Certain special chemicals in plants have great value to man. This always has been the case so far back as history can trace, and nowadays, with scientific methods available, many such plants are specially cultivated on account of the product peculiar to them. Strange to relate, the majority of these economically important plants are native to tropical and subtropical lands only.

They cannot all be considered, but a few will give some idea of their diversity of nature.

Latex and Rubber

In certain plants, apart from the water-conducting tissue called xylem, and the food-conducting tissue called phloem, there is another tissue somewhat like these. This is called the **laticiferous** tissue. It is composed of long tubular structures, which branch throughout nearly the whole of the plant. These tubes contain a colloidal substance called **latex**, which differs with the different plants in which such tissue is found. The use of the laticiferous tissue to the plant itself is not quite clear.

The colloidal latex of some plants has proved useful to man in the past and, in some cases, certain types of latex are of great value to-day. One very familiar example of latex is of very little value to man; but it is so common that it is worthy of mention. That is the latex of the common dandelion (*Taraxacum officinale*). Throughout the roots, stems and leaves of this plant there is a

laticiferous tissue which contains a white, milky latex (Fig. 211). Naturally, if the leaves are broken, and especially if the stalks are, the laticiferous tissue is ruptured and the latex flows out. This is easily seen at the end of a broken dandelion stalk. Dandelion latex is of no use to man, although, in the country, some people put it on warts. It is supposed to cure them; though this is doubtful.

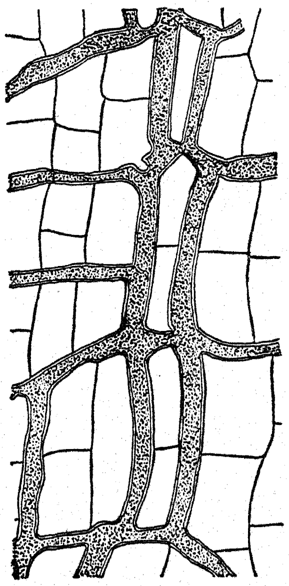


FIG. 211. TANGENTIAL SECTION THROUGH THE CORTEX OF THE ROOT OF THE DANDELION, SHOWING LATICIFEROUS TISSUE.

Another latex, familiar to country people, is that present in many poppies. This is a reddish-brown in colour, and is a very bad stain. When picking ordinary field poppies, this latex, from the broken ends of the stems, gets on the hands and stains them. The stain is not easily got rid off, and sometimes stays on the hands for days. A foreign species of poppy (*Papaver somniferum*) produces a latex which contains the drug called **opium**. This is of value to man, and will be considered later.

The most important latex from the economic point of view is that produced by the **rubber** plant. It is scarcely necessary to emphasise the importance of rubber to-day. It is the chief asset in the manufacture of tyres of all descriptions, some footwear and clothing, electrical apparatus, submarine cables, and it has even been tried as a form of street paving, but this is still in the experimental stage. Rubber is now being exploited as a textile. Girdles and elastic collars and cuffs are being manufactured from it. It is also being used in the manufacture of unbreakable dishes and other household utensils.

Rubber is produced from the latex of several different plants, all of which grow in wet, tropical forests. The actual use of the

latex to the plants themselves is probably as a protective agent against parasitic insects. The naturalist **Thomas Belt**, who published an account of the natural history of Nicaragua in 1874, stated that in those plants which had been drained dry of their latex by the native Indians of that part of America he found thousands of beetles, whereas in the untouched trees there were none.

The history of the rubber latex dates back a long way. During

FIG. 212. NATIVES COLLECTING LATEX FROM THE RUBBER TREES IN MALAYA.
(By courtesy of Messrs. David Bridge and Co., Ltd.)

his second visit to America in 1493, Christopher Columbus saw the native Indians, in the Amazon valley, playing with a ball made of rubber. He was struck chiefly by the manner in which the ball rebounded. Yet in spite of this remarkable observation, more than three centuries elapsed before rubber became of any commercial value in the Old World. Then it was used only for erasing marks off paper ; hence the name **india-rubber.**

Several plants form sources of rubber, but the chief one is a tree called *Hevea brasiliensis*, which supplies the well-known Para rubber. Another which supplies a considerable amount of the world's raw rubber is *Dyera costulata*, which is native to Malaya.

One which is grown in British gardens as an ornamental shrub is *Ficus elastica*, commonly called the india-rubber tree. Nowadays, the various rubber trees are cultivated in plantations. The chief sources of supply are the East Indies, Central and South Africa, Burma, Malaya, Assam, Mexico and Central America and Brazil (Fig. 212).

FIG. 213. TAPPING A RUBBER PLANT.
(From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.)

The trees are tapped for latex when they are about five years old. Tapping is done by taking off a shaving of the bark of the tree (Fig. 213). This cuts the latex tubes, and the latex then flows out. Tapping is performed early in the morning, when the flow of the latex takes place at its greatest rate. Collecting cups are placed beneath the wound and left there to collect the latex.

After a few years the wound is healed by the development of a fresh covering of bark, and the tree is ready to be tapped again, in the same place if necessary.

The latex is then removed to the factories, where it is purified and the rubber manufactured from it.

It is interesting to note what a difference the development of automobile transport has made on the production of rubber throughout the world. Between the years 1900 and 1911, the annual increase in the world's rubber production was at the average rate of 3000 tons a year. Then there was a great deal of activity in the production of tyres to satisfy the demand of the motor-car industry, with the result that the average increase in rubber production rose to 34,000 tons a year. In 1927 the world's production of rubber was 623,000 tons.

The Government of the U.S.S.R. is encouraging research work on a plant named *Chondrilla*, closely related to the dandelion. The plant contains a latex which can be converted into a rubber. Experiments have been made to test the practical side of this method of obtaining rubber, and thus avoid the necessity of importing large quantities of rubber from tropical countries.

Tobacco

Tobacco, in the form of the rolled leaf, is smoked in cigars, and, cut up into shreds, it forms the most important material for pipes and cigarettes. One only has to see the large number of men and women who smoke tobacco to-day, in all parts of the world, to realise what a tremendous number of plants must be grown in order to meet such a demand. Some people, and especially natives of Africa and also the American Indians, chew tobacco, and some even eat it. In the eighteenth and nineteenth centuries it was popular in powder form, when it was inhaled at the nostrils. In this form it was called **snuff**. This form of tobacco is not now in great demand.

Columbus noticed the Indians in America using tobacco, when he visited them on both his voyages to that continent, in the latter part of the fifteenth century. Tobacco was only one of the plants smoked by American Indians, however ; powdered willow bark was another.

The tobacco plant is a native of Central America. It was brought to Europe in 1558 by a Spaniard named Francisco Fernandes, and was later popularised in England by Sir Walter Raleigh, who is said to have smoked a pipe of tobacco on his way to the scaffold.

The main supply of the world's tobacco is obtained from the leaves of the tobacco plant, *Nicotiana Tabacum* (Fig. 214). This is an annual plant which attains a height of about five feet. It

FIG. 214. A FIELD OF TOBACCO BEING CULTIVATED UNDER CHEESE CLOTH IN SOUTH AFRICA.

terminates in a large inflorescence of pink flowers. The leaves are long and shaped like the head of a lance. Sometimes they reach a length of two feet. It is the leaves, of course, which supply the tobacco as we know it.

The chief source of the tobacco plant is the United States, chiefly in the State of Virginia. But the plant is actually cultivated for the purpose in a large number of other places ; for example, Brazil, China, Japan, Dutch East Indies, Canada, Cuba, Africa, Turkey, Egypt, U.S.S.R., Germany, and even in certain parts of Great Britain. Even in the days of Cromwell the plant was cultivated in England. To-day its cultivation is restricted to certain parts of Hampshire, because the English climate

is not favourable to the growth of the plant, although it is often grown for decorative purposes in herbaceous borders. Naturally, since the greatest plantations are in America, the bulk of the tobacco smoked is American. This is commonly called Virginian tobacco, and is present in the majority of the more familiar cigarettes and cigars. Egyptian cigarettes and also Turkish are stronger in flavour, and are usually treated with a perfume. Russian cigarettes are stronger still.

As the leaves of *Nicotiana* begin to ripen, they turn a brighter green and sometimes become covered with yellow spots. They are then stripped off the plants, and hung on long sticks in sheds to dry. Then they have to be 'cured.' In favourable districts, such as Virginia, they are cured by merely exposing to the sun. Often, however, curing sheds are necessary and, if the weather is at all damp, fires must be used. Then the leaves are piled into heaps, where they are allowed to ferment. This fermentation process is helped by enzyme action. The enzyme is usually supplied by certain bacteria already present in the tobacco leaf. After fermentation the leaves are tied up into bales and graded. Then they are stored, when the tobacco matures.

The amount of tobacco smoked in various forms can be imagined from the fact that the world's annual production of tobacco is more than 4,000,000,000 lb.

Perfumes

The perfumes of certain flowers have been used for the production of certain scents through every historic age. A large number of flowers give off delicate perfumes ; but only a comparative few have achieved universal popularity, such as the rose (*Rosa*), violet (*Viola odorata*), lily of the valley (*Convallaria majalis*), lilac (*Syringa vulgaris*), etc.

The perfume of flowers is due to an oil present in the petals in very small quantities. Sometimes this oil is present in the free state, for example, rose and lavender (*Lavandula vera*), whereas in other cases it is present united chemically with glucose, thus forming a glycoside, as in the case of jasmine (*Jasminum*). The most familiar perfumes of commerce prepared from such oils of flowers are: carnation (*Dianthus*), clove

(*Eugenia*) (Fig. 215), hyacinth (*Scilla*), heliotrope (*Heliotropium*), mimosa (*Mimosa*), jasmine, orange blossom, rose, violet, and ylang-ylang (*Cananga*). In other cases the perfume is present in the flowers and the leaves, such as lavender, rosemary and violet. Other well-known perfumes and flavourings are present in vegetative organs only, for example: leaves and stems, geranium and cinnamon ; bark, cinnamon ; wood, cedar and sandal ; root, angelica ; rhizome, ginger ; fruit, lemon, orange ; etc.

In early times the perfume was extracted by dissolving it out with olive oil or almond oil. To-day it is extracted by a method of distillation which takes the form either of boiling the plant material with water or forcing steam through it. In many cases, however, this method is useless because the high temperatures involved chemically decompose the oils of the perfumes. Then another method is used. This involves the use of some form of animal fat. The fat is spread on sheets of glass. Then the petals of the flowers are stuck on the fat, and the glass sheets piled on top of each other, and allowed to remain for a few days, during which time the perfume dissolves into the fats. Then fresh petals are placed on the fat and the process repeated. The resulting perfumed fat then forms a **pomade**.

Another method makes use of the fact that ether dissolves plant oils. The plant material is placed in sealed vessels, and the ether allowed to pass slowly through it. As it does so, it dissolves out the perfume, together with other plant oils and any plant waxes present. The ether solvent is then driven off and the residue purified. The resulting oil is then in a very concentrated form. From it the perfumes of commerce are made up. The most expensive perfumes are made in this way ; for example, in the case of jasmine, the jasmine oil produced will fetch anything from £3 to £6 an ounce.

Plant perfumes are manufactured on a large scale chiefly on the Continent and in the Near and Far East. Grasse, a town in France, is widely known for its perfumes, especially those manufactured from oranges and roses. **Attar of roses** is prepared in India, Persia, France and the Balkan States. The oil produced is very valuable, costing sometimes so much as £60 per pound.

The tremendous quantities of roses grown can be imagined when one realises that 4000 lb. of rose flowers are required to produce 1 lb. of the attar.

Spices

Certain **spices** and **condiments**, especially useful in cooking and in medicines, also **cosmetics** used for cleansing, purifying and beautifying the skin, are of interest, since the majority of them are the products of special plants.

A historically interesting plant perfume, used in ancient days as a cosmetic, is **spikenard**. This was obtained from the rhizome of the spikenard plant (*Nardostachys Jatamansi*), a native of India. As a cosmetic, spikenard is of scarcely any value now. But in the olden days it was very valuable, costing the equivalent of £10 per pound. It was used by the ancient Romans and Egyptians, and even in ancient Palestine, for it is mentioned in the New Testament (Mark xiv. 3-5). In those days, this valuable plant product was taken by camel caravans from India to Rome, Egypt, Palestine, etc.

Two products, which at one time were of great importance, are produced from the natural gums present in certain plants. These are **frankincense** and **myrrh**. Both these plant products were of great importance to the people of ancient Egypt, and to all the countries around, many hundreds of years before the birth of Christ. Their value, however, was maintained right up to this era, since we read in the New Testament that the wise men who visited the child Jesus brought with them gifts of gold, frankincense and myrrh.

Frankincense is obtained from the gums present in certain species of the trees called *Boswellia*. These plants are native to India and Africa. Even in early times, frankincense was a valuable spice, and there was a great trade in it amongst the countries of the Near East and India. Its value lies in the fact that it burns, giving off a smoke which is pungent, yet of a fascinating odour. It was used for this purpose in the substance called **incense**. Incense was burned during the religious rites of the Egyptians, and also by Jews and Christians. To-day it is still used to a great extent during the rites of certain religious sects, such as

those of the Jews, Roman Catholics, many Anglican Churches, the Greek Orthodox Church, and so forth.

Myrrh, another spice of great value during those early days, is a product of the natural gum of several species of *Commiphora*. The plant is native to eastern Africa and Arabia. It was used during ancient times, and still is, as another constituent of incense; but it had a still greater value in that it was one of the chief spices used in embalming mummies, especially during the time of the ancient Egyptians.

Two spices used to-day in cooking and medicine are the **clove** and **cinnamon**.

Cinnamon is obtained from the bark of the plant *Cinnamomum zeylanicum*, a native of Ceylon. The plant, however, is now cultivated in other countries, such as Java, Egypt, and Brazil. The sweet taste and pleasant aroma are due to an oil present in the bark. This spice was prized in the days of ancient civilisations. To-day it is used as a condiment and flavouring material in cooking and also for flavouring certain types of chocolate and liqueurs.

FIG. 215. *Eugenia caryophyllata*, SHOWING A FLOWERING BRANCH AND (EXTREME LEFT) A BUD, THE CLOVE, CUT IN HALF, AND (MIDDLE) AN OPEN FLOWER.

Cloves are the dried, unopened flower buds of the plant *Eugenia caryophyllata* (Fig. 215), a native of the Moluccas, or Spice Islands. This spice was a valuable article of trade in the Oriental countries of the past. To-day it is cultivated in many parts of the world, including India, South America, and Africa. The cloves in the dried condition are used as a flavouring material in cooking, and in the making of confectionery and liqueurs. This spice also contains a valuable oil. Oil of cloves, as it is called, is used as a medicine, and dentists often use it as a local anæsthetic instead of cocaine. It is also useful in the laboratory in the preparation of microscope slides, etc.

Condiments

Two important condiments which are the products of certain plants are **pepper** and **mustard**.

There are several pungent condiments classed as peppers; but the three most commonly used are **black, white** and **Cayenne**

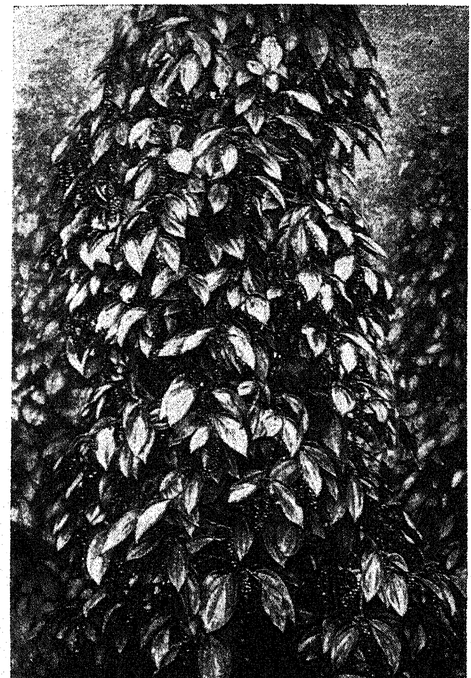


FIG. 216. PEPPER PLANT.

pepper. Black pepper is the powdered dried fruit or pepper-corn of a climbing shrub, *Piper nigrum* (Figs. 216 and 217), native to Malabar. Now it has been introduced for cultivation into other countries, the chief of which are Malaya, Java, Sumatra, Borneo and the West Indies. The plant climbs on trees in a manner similar to that of the ivy. Black pepper owes

its pungency to the resin which it contains; and its flavour to an oil. It also contains an alkaloid called **piperine.** Black pepper is used solely as a condiment. It is one of the oldest condiments known to mankind.

White pepper is prepared from the same source, but the dark skins of the fruit are removed first. It has a better flavour, and is less pungent than black pepper. Cayenne pepper is red in colour and very pungent. This is prepared chiefly from the dried fruits of the plant *Capsicum annuum*, but other related plants are sometimes also used. These plants are herbaceous in some cases and shrubby in others. They are all native to Central and South America. The cultivation of the cayenne pepper plants is not so widespread as that of those plants producing white and black pepper, because there is not such a great demand for the product. However, the cayenne pepper plant has been introduced into the East Indies for cultivation. The dried fruit of *Capsicum annuum* is red in colour, and is often used whole instead of being powdered. This dried fruit is called the **chilli**, and is used in making chilli-vinegar and also in flavouring pickles.

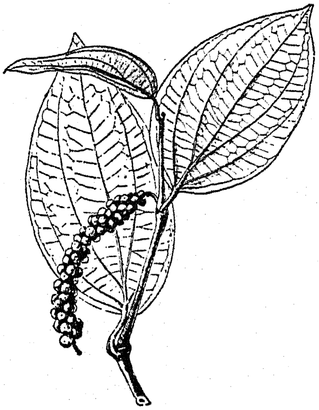


FIG. 217. LEAVES AND FRUIT OF PEPPER PLANT.

Mustard seeds are produced by several species of plant named *Brassica*. There are several forms of mustard, but the two important ones are black mustard (*Brassica nigra*) (Fig. 218) and white mustard (*Brassica alba*). Both plants are cultivated in England, the white mustard plant often being used, in the very young stages, in green salads and sandwiches. Black mustard, on the other hand, is never used for salads. It is cultivated only for its seeds, from which the condiment is prepared. Both these plants grow wild in Great Britain, on the Continent, in Canada and in the United States.

The pungency of mustard is due to an oil. It is interesting to note that the oil is not present in sufficient quantity in the seed or the dried powder to give this pungency. Only when the mustard is prepared for the table, by adding water to it, does the oil appear, for this reason: the mustard seed contains a glucoside called **sinigrin**. It also contains an enzyme called **myrosin**. This enzyme can act on the sinigrin, and cause it to split up chemically into the oil to which the mustard flavour and odour are due, together with glucose and a potassium salt. But the action of the enzyme can only take place in presence of water. At a very high temperature, for example, that of boiling water, the enzyme action is killed. For that reason it is undesirable to prepare mustard for the table with very hot water.

FIG. 218. BLACK MUSTARD.

Mustard is also used for medical purposes. The use of mustard plants, both for the production of the condiment and for medical purposes, has been known from the early times. It is on record, for example, that the ancient Greeks used it.

Tea

The three most popular hot drinks in Great Britain are **tea, coffee** and **cocoa**; and they are all plant products.

Tea is the dried leaves of the tea plant (Fig. 219), a shrub now

cultivated for the purpose in several parts of the world. The early history of tea as a beverage is not known for certain. Most probably it originated in China, where tradition has it that it was discovered by the Emperor Shên-nung in 2737 B.C. From China, knowledge of the stimulating properties of this drink passed westwards to India in the sixth century and eastwards to

FIG. 219. A FLOWERING SHOOT OF THE TEA PLANT, AND A SEED AND FRUIT.

Japan, where cultivation of the shrub was begun in the ninth century. It was not until the middle of the seventeenth century that the English began to use tea, and then it was such a luxury that it cost about £8 per pound. Since then, of course, it has become an everyday beverage, with the result that the large demand for it, not only in Great Britain but also throughout the world, especially the Eastern countries, has made tea cultivation an industry of gigantic proportions.

In 1834 it was proved conclusively that the tea plant is also a native of Upper Assam. To-day tea is cultivated all over India, in Ceylon, Japan, certain parts of Africa, Java and Sumatra.

The tea shrub is an evergreen, growing normally to a height of 3 to 5 feet. The stem is heavily branched, and the branches bear small elliptical leaves. The plant is closely related to the camellia plant. Its botanical name actually is *Camellia Thea.*

For good results the plant is usually cultivated on hilly slopes facing the sun. This is because it requires plenty of light, a warm, subtropical climate, and a damp atmosphere with plenty of rain, though a well-drained soil.

An important process during cultivation is **pruning**. This involves cutting off the branches when the shrub is about two years old. The result is similar to that in the case of pollarding and coppicing in that the dormant buds shoot out, thus producing a plant with a large number of short branches, each thick with leaves. Once pruning is commenced, it is usually carried out annually.

When the plant is well established, plucking the leaves takes place about once every 10 to 14 days, and there are about 25 pluckings each year.

The preparation of the dried tea as we know it involves several important processes. The plucking is usually done by native men and women (Fig. 220). The leaves are then taken to the withering shed, a shaded room, where the leaves are spread out on trays or on the floor to **wither**. They are considered to be sufficiently withered when they are soft and limp. Then the withered leaves are **rolled**. This involves placing them between two metal surfaces and rubbing them. This process takes between 30 to 60 minutes. After that time, the rolled leaves are sifted, and the older ones rolled again if necessary. The next stage in the process is an important one, for it gives flavour and colour to the final product. This is the process of **fermentation**. The rolled leaves are spread out in layers of about two inches in thickness, in sheds where there is easy access of air. Fermentation is helped by the enzymes which naturally occur in the leaf. During fermentation, the leaves turn a bronze colour. This is due to the tannins present in the leaf. The tannins in the living leaf are

colourless, but during fermentation they become oxidised by the oxygen in the atmosphere, and in doing so assume a bronze colour. When it is necessary to stop fermentation the leaves are quickly **dried**. This is done by placing them on moving tables in a room through which a current of hot air is being forced. Drying takes about half an hour.

FIG. 220. NATIVES GATHERING TEA.

Throughout the world about 900,000,000 pounds of tea are consumed annually. This gives some idea of the gigantic size of the industry. Scientific workers prove invaluable to the maintenance of the industry, since the tea plant has its share of insect and plant parasites.

Coffee

Coffee is the product of the coffee plant (*Coffea arabica*), a native of Abyssinia, which, however, is now extensively cultivated in several parts of the world, especially Brazil, southern Arabia, the West Indies, East Indies, India, Sierra Leone and the Congo (Fig. 221). Other species are used, but they are of

inferior quality. Coffee production in Kenya Colony is a fast-developing industry to-day.

The plant is an evergreen shrub attaining a height of about 20 feet. The fruit of the coffee plant is a fleshy berry, something like a small cherry in appearance. Inside each berry are two seeds, and these seeds are the raw material from which the coffee is obtained (Fig. 222). They are commonly called coffee beans, though really they are not a bit related, botanically, to the beans with which we are more familiar. When ripe, the seeds are hard and greenish in colour.

FIG. 221. HARVESTING COFFEE.
(By courtesy of Mr. J. P. Ugarte, Messrs. E. H. Bentall & Co., Ltd.)

The history of coffee as a drink dates back to obscurity. We know very little of its early history, but it is known that it was a popular drink in Abysinnia in the fifteenth century. Coffee became popular in Europe during the seventeenth century, when coffee-houses sprang up almost as thick as the tea-shops and restaurants of to-day. The earliest known coffee-house in England was opened in St. Michael's Alley, Cornhill, London, in 1652.

The coffee plant is cultivated from the seed, and begins to bear its own seeds suitable for coffee production after the fifth year. When ripe, the fruits containing the seeds are either allowed to drop of their own accord or are gathered by hand.

After the seeds have been extracted from the fruit, they are usually shipped abroad as coffee beans. Then they are either roasted in factories or even in the grocer's shop. After roasting, the beans are ground to the familiar coffee powder. The stimulating action of coffee is due to an alkaloid present in the seed called **caffeine**. This alkaloid is also present in tea, but not to such a great extent. The aroma of coffee is due to an oil present in the seeds called **caffeone**.

FIG. 222. *Coffea arabica*. A flowering shoot, a fruiting shoot, a single flower, a single seed, and two seeds with part of the fruit wall removed.

Coffee plants have their diseases which demand the attention of scientific workers in connexion with the industry. The most important one is caused by a fungal parasite, *Hemileia vastatrix*, which attacks the leaves of the plant, causing the disease known as **coffee-leaf disease**. This disease broke out in epidemic form in Ceylon towards the end of the nineteenth century, as mentioned in Chap. XIV. That epidemic will always be remembered in the industry, since it was a real tragedy, absolutely ruining the crops of Ceylon and involving the industry in a loss of more than £15,000,000. Since that time, the disease has spread to other coffee-growing countries, but scientific workers have it under better control now.

Cocoa

Cocoa is made from the seed of the **cacao tree** (*Theobroma cacao*), a plant native to tropical America. For its great commercial value, however, the plant is now cultivated in many other tropical regions.

The seeds of cacao are borne in a long pod, shaped like a ridged, elongated, lemon. These pods are produced directly on the main trunk and branches in an unusual fashion (Fig. 223). For cultivation, the seeds are sown in nurseries, then later on

the seedlings are transplanted into the cacao plantations. After about five years, the young trees begin to bear fruit. Harvesting goes on all the year round, but there is usually one period of the year when the harvest is at its best (Fig. 224). This period varies with the country in which the cacao is cultivated; for example, the heavy season in Ecuador is April to June, whereas in Brazil it is September and October.

FIG. 223. CACAO PODS GROWING ON THE TREE.
(By courtesy of Messrs. Cadbury Bros., Ltd.)

After harvesting, the beans are extracted from the pods and placed in boxes to undergo fermentation. This takes 2 to 9 days according to the variety of the cacao and the country in which it has been grown (Fig. 225). After fermentation, the beans are dried. This is usually done in the sun by spreading them on brick or wooden floors, or on coco-nut or bamboo mats. Then very often the beans are polished, but there is no real reason for this except that they look more attractive to the buyer. The beans are finally roasted and powdered to produce the cocoa as we know it.

The chief cacao-cultivating regions are in Africa and America. The Gold Coast produces by far the most, but other important areas are Nigeria, Brazil, Trinidad, Ecuador and Venezuela.

Cocoa has a high nutritive value, and it is mildly stimulating, since it contains a certain amount of the alkaloid caffeine, though not so much as coffee does.

FIG. 224. HARVESTING CACAO PODS.
(From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.)

Medicinal Plants

Even in early days, primitive man was much interested in plant life, as indeed the natives of tropical Africa and America are to-day. Though such people never actually cultivated plants, they must have known a great deal about them, using many for food, and discovering which ones were poisonous, and even those plants which had medicinal properties.

Gradually, as they learned more about curative herbs, certain members of primitive tribes began to specialise in the preparation of decoctions. These men were called **medicine men** or **witch doctors,** and their knowledge commanded so much respect from other members of the tribe that they were feared. Many of the 'curative treatments' to which they subjected their

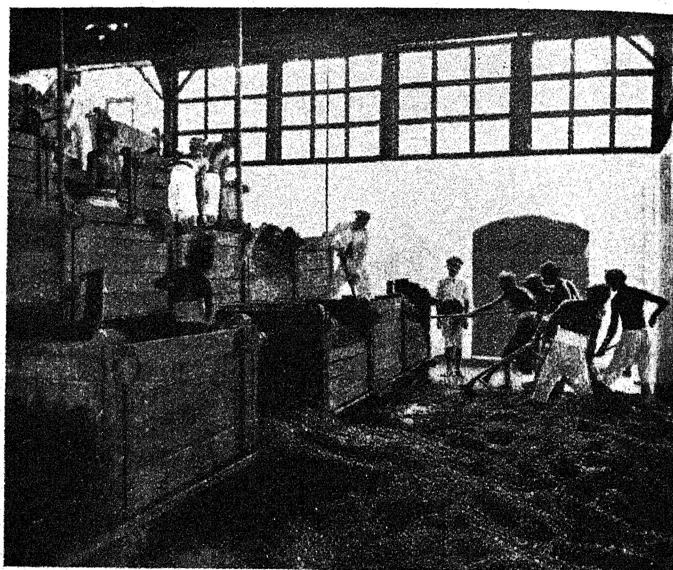


FIG. 225. CACAO FERMENTATION BOXES AT JAVA.
(*Photo. Hisgen.*)

patients were futile, yet these 'doctors' were familiar with a large number of plants which contained genuine curative substances.

Profound belief in these medicine men is a long time dying out; in fact, such witchcraft still holds sway over many tribes in Africa. Something similar was present amongst the ancient tribes of the temperate countries. In this case, the study of herbs and their curative effects was chiefly left to the women. To read Shakespeare's *Macbeth* is sufficient to give an idea of

the decoctions that these old women used to make up. There we read of such medicines as "scale of dragon," "tooth of wolf," "gall of goat," "slips of yew," "root of hemlock digg'd i' the dark," and so forth.

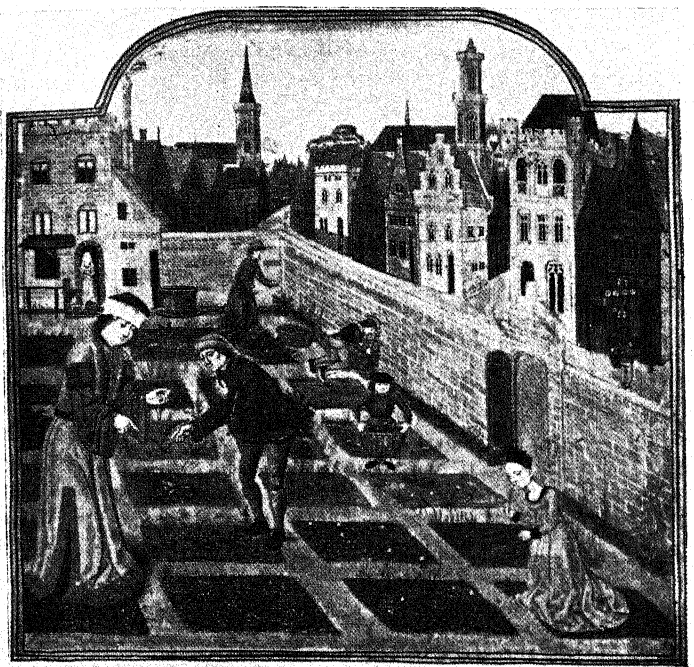


FIG. 226. A MEDIEVAL HERB GARDEN.
(From Petrus Crescentius' "Opus Ruralium Commodarum.")

As the study of medicine developed, the supposed curative effects of plants were gradually brought into question, and the genuine cases sifted from the mythical. Then, the earlier botanists studied plants from scarcely anything but their medicinal point of view, and herb gardens were cultivated (Fig. 226). Now, to-day, medical men make use of many drugs and other medicines produced from plants.

Drugs

Many medicinal plants grow in Great Britain, but it is impossible to mention even a small fraction of them now. It is therefore proposed to consider just a few such plants, all of which are of foreign origin.

There is a group of chemical substances which are very complicated from the point of view of the elements they contain, but, since they act like alkalis (though really not alkalis), they are called **alkaloids**. All these alkaloids are potent drugs, some of which are useful from the medical point of view. Very few of them can be made artificially in the laboratory, but they all exist naturally in certain special plants. Alkaloids are not widely distributed through the plant kingdom.

FIG. 227. *Cinchona succirubra.* (*After Schumann and Arthur Meyer.*)

A very important alkaloid is **quinine**. This is a very familiar drug. It is used for preventing colds, for killing the malarial parasite in the blood of a patient suffering with that disease (in this respect, quinine proved a great boon during the Crimean War, and in all wars since), and for killing many of the bacteria which are responsible for diseases in man. Our knowledge of the medical uses of quinine is due chiefly to the great work of **Prof. Binz**, of Bonn, in Germany.

Quinine is an alkaloid present in the bark of the tree called the *Cinchona* (Fig. 227). The earliest record of the medical use of the cinchona bark dates back to 1638, when it was used effectively for curing the Countess of Chinchon, the wife of the Governor of Peru, of a fever. From this the plant got its familiar name. At

that time cinchona trees grew only in South America; but gradually the fame of its bark was spread throughout Europe, chiefly by the monks of the time, who were also the doctors. Then, in 1854, the Dutch Government obtained some trees from South America and transplanted them to Java. Similarly, in 1859, the British Government transplanted some to India and Ceylon. To-day, cinchona plantations exist in all those countries,

FIG. 228. *Cinchona* PLANTATION, FOUR YEARS OLD, AT SIKKIM. (*From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.*)

solely for the production of quinine (Fig. 228). The world's chief supply, however, comes from Java. Quinine, like all other alkaloids, is a drug, and therefore if taken in excessive quantities has a bad effect. Some alkaloids are deadly poisons when taken in excessive amounts.

Another alkaloid, very valuable to the doctor as a drug, is **strychnine**. This was first discovered in 1818 in St. Ignatius's beans and other related plants, all named under the heading *Strychnos* (Fig. 229). Strychnine is obtained from the wood and the bark of the various species of *Strychnos*. Though this is a

very important drug from the medical point of view, it should never be used except under the directions of a qualified doctor, for actually strychnine is a strong and deadly poison. Taken in strong doses, this plant alkaloid can cause the death of a person in half an hour. It is used in certain vermin-killers owing to its strong toxic action. Savages even knew of the poisonous nature of this plant, and they used it for smearing the heads of their poisonous arrows. Large animals, when pierced by an arrow bearing strychnine, almost immediately stagger and are dead after having taken only a few steps.

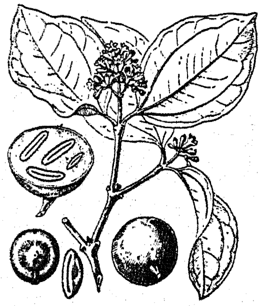


FIG. 229. *Strychnos nux vomica*, SHOWING ALSO THE FRUIT AND SEED, WHOLE AND IN CROSS SECTION.

Cocaine is another alkaloid of great use both to the doctor and the dentist. This alkaloid exists in the leaves of the **coca** plant (*Erythroxylon Coca*) (Fig. 230). The plant is native to Bolivia and Peru; but to-day it is cultivated for the sake of the drug, in Java. Cocaine is a potent drug. It is used by medical and dental surgeons because, when injected into the tissues of the body, it acts as a local anæsthetic, thus deadening the tissues to pain. Therefore, it may be injected for slight operations, such as some skin operations, or in the gums for drawing a tooth. It deadens the tissues just around the seat of pain, without completely anæsthetising the patient, as chloroform and ether do.

If taken internally, cocaine deadens any sensation of hunger in the stomach, with the result that the person can go a long time without feeling the need of food. Moderate doses of the drug produce a sensation of calmness and happiness, and that is why some people, when they can get it, take it. But modern legislation makes it difficult for any unauthorised person to obtain cocaine. To sell it, or supply it at all without a special permit, is a criminal offence, for the drug demoralises such people and sooner or later a small dose does not have the required effect. Then larger doses are taken, with the result that they affect the

nervous system. This leads to mental depression, physical laxity and finally insanity.

The latex of the poppy, *Papaver somniferum*, as we have already seen, also contains a drug called **opium**. This contains several alkaloids. The drug is usually extracted from the fruit of the

FIG. 230. *Erythroxylon Coca.*

poppy. The only wild opium poppy grows along the northern shores of the Mediterranean Sea; but it is cultivated in many parts of the world, such as France, Germany, Turkey, Persia, China and the United States.

From the medical point of view, opium is very valuable owing to some of the alkaloids it contains. On the other hand, this drug is a great menace because it has the same effects as cocaine

when taken without the supervision of a doctor. Opium-smoking is a well-known habit of the Chinese.

The chief alkaloid of medicinal value present in opium is **morphine.** This drug has a great pain-relieving power and also induces deep sleep. There is not another plant drug known which has such a great power of relieving pain as morphine. For this reason it is the most common drug in use in hospitals. It is injected, usually by means of a hypodermic syringe, beneath the skin, usually of the arms when possible, of patients who are suffering from excessive pain or who cannot sleep.

The leaves of *Nicotiana* (the tobacco plant) contain an alkaloid called **nicotine.** This is therefore present in tobacco itself. Like the other alkaloids considered, in large doses it is a deadly poison, and that explains why excessive smoking in adults, or smoking at all in young people, should be deplored. Nicotine is still used in medicine, though not to any great extent. Its greatest value lies in its use to horticulturalists. Spraying mixtures called **fungicides** have already been mentioned. These are used for killing fungal parasites on horticultural crops. Other spraying mixtures, called **insecticides,** are used for spraying crops attacked by insect parasites. The chief constituent of many insecticides is nicotine.

Vitamins

Right up to the eighteenth century, one of the most dreaded diseases amongst sailors was a disease called **scurvy.** This disease almost always ended in death. It was so common that no mercantile or naval ship could go to sea for weeks at a time without, on its return, reporting the death through scurvy of a number of its crew. The same disease was prevalent in prisons and workhouses. The conditions under which sailors, prisoners and paupers lived were similar in at least one respect. That was the absence of fresh food. Naturally, in those days, since they had not the advantages of modern science, it was impossible for ships to take fresh fruit and vegetables on their long journeys.

So long ago as 1593, the great sailor, **Sir Richard Hawkins,** recognised that scurvy could be curtailed in its ravages if fresh

fruit and vegetables were only available ; but, realising how impossible this was on long journeys, he noted that to take an essence of fresh fruit in the form of orange and lemon juice had a wonderfully beneficial effect. Nevertheless, it was not until two hundred years after that the idea was followed up. The annual deaths in the navy due to scurvy were appalling. In fact, the disease was almost as common as the common cold is to-day. However, owing to the great physician, **Dr. James Lind,** who did so much brilliant work in connexion with hygiene in the British navy, an Admiralty order was given, in 1795, that all ships should be supplied with lemon juice. From that day, scurvy disappeared from the navy.

In India, Malaya, China and Japan, a disease which ravages the native population is one called **beriberi.** Now the natives of those countries live, as is well known, almost completely on rice. After much research work on the part of many men of science, it was discovered that the disease was more common to those people who ate polished rice, that is, rice from which the outer coating of the grain had been removed. It was then discovered that just as in the case of oranges and lemons, which must contain something which prevents scurvy, so do the fruit coats (pericarp) of the rice grain contain a substance which prevents beriberi.

Both these diseases, in other words, are due to a certain deficiency in diet. They are therefore called **deficiency diseases.** There is quite a number of these diseases.

It is interesting to note a more modern example of the effect of scientific discovery on man's life and activities. In 1931 a scientific expedition of young British men, under the leadership of the late Mr. H. G. Watkins, set out for the arctic regions, to try to discover an arctic air route over Greenland. They realised that they would suffer much privation and a severe lack of fresh plant food. They therefore went well supplied with concentrated lemon juice. One special incident during the expedition is worthy of note. Mr. Courtauld, one of the members of the party, was left for several months almost buried in a snow hut, for the purpose of making important observations on the weather. He was alone all that time, yet, when finally relieved,

was in perfect health. Going all that length of time would almost certainly have left its mark on his health if he had not made sure of his diet; and he himself ascribes the maintenance of his good health to the concentrated lemon juice he had taken with him.

It is clear from these observations that certain plant materials contain definite substances which help animals to develop correctly, and also to maintain good health. These chemical substances are called **vitamins**. The inclusion of an adequate supply of vitamins in the diet of all animals is therefore necessary in order to keep such animals healthy. This is especially so in the case of young, developing children. Such a supply of vitamins ensures good growth and development, prevents deficiency diseases such as scurvy, rickets, beriberi, and stimulates a healthy formation of the teeth, bones, etc.

It is clear that a study of the nature of vitamins is of the utmost importance. Actually, we have a great deal to learn about them; but so many scientific workers are now attacking this problem all over the world at the present time, that new information is being brought to light almost every day. In Great Britain, much of the pioneer work on vitamins was done by **Sir F. Gowland Hopkins** at the University of Cambridge, from 1906 onwards.

Many plants manufacture vitamins. At one time it was believed that the vitamins, like many other substances of nutrition, could be manufactured *only* by plants, and that animals obtained them by consuming the plants. This is one example concerning vitamins which shows how quickly the work on them is moving, for so recently as 1922 this was believed. Now we are certain that animals can manufacture certain of their own vitamins, given suitable conditions, without absorbing them from plants.

Up to the year 1922 only two vitamins were definitely known. They were called **vitamin A** and **vitamin B**. Now, we are certain of several others.

Vitamin A is a growth-promoting vitamin. Without it, animals cannot develop properly. In experimental work, animals have been kept strictly on a diet containing none of this

vitamin. Gradually the animals showed a poor growth and finally stopped growing all together, lost weight and then died. This vitamin has been shown to be present in many plants and animals. It is present in especially large quantities in the liver of fishes. This is why cod-liver oil is so often taken by children. It ensures their having a sufficient quantity of vitamin A, thus stimulating good growth and development. Vitamin A is also present in green leaves. It has been shown that the outer leaves of certain varieties of lettuce are 30 times richer in vitamin A than the inner leaves. Until quite recently, it was believed that this vitamin could not be manufactured by animals and that fishes, for example, absorbed it into their systems from the various sea-plants they consumed. Now we know that this is not the case.

There is a very close relationship chemically between this vitamin and carotene (the pigment present in the green colouring matter of leaves and also in abundance in the roots of carrots). It has been shown that the chemical relationship is so close that if animals can absorb carotene, they can make vitamin A from it, in their own bodies.

What was at one time called **vitamin B** is now known to be composed of several vitamins. Two are definitely known. One, called **vitamin B_1**, is the vitamin which prevents beriberi. Therefore this vitamin is present in the pericarp of the rice grain. **Vitamin B_2** has the property of preventing certain other skin diseases, such as that called **pellagra**. It is present in many plant and animal products, such as yeast cells, egg white, wheat grains and tomato fruit.

Vitamin C is the one which prevents scurvy and other related diseases. This vitamin is present in certain parts of plants, especially green leaves, such as the cabbage ; in fruit, such as lemons, oranges, grape fruit and tomatoes ; and in certain roots, such as that of the swede. Work on vitamin C carried out at Cambridge in 1933 has brought to light certain facts of great interest. It was shown that lemons, oranges and grape fruit contain about equal amounts of this vitamin but other plants vary. The banana fruit, for example, contains about five times as much vitamin C as lemons, etc. ; carrot roots, about twenty

times as much, and cow's milk about thirty-five times. Also certain parts of the same fruit vary in their vitamin content, as, for example, the apple. There, the main parenchymatous tissue contains about five times that of the peel.

Vitamin D is a highly interesting one. This is the agent which prevents malformation in the skeleton of animals. One disease due to such malformation is called **rickets**, which results in all kinds of deformations of the body. Vitamin D is present in the liver of fish, in butter, milk and yeast. It is, however, very interesting in that it can be manufactured in the animal body, without the animal depending upon plants for it. The main condition necessary for its direct manufacture in the animal is plenty of sunlight. That is why plenty of sunshine is so good for the average animal. Those rays of the sun which cause the animal to manufacture its own vitamin D are the ultra-violet rays. These rays can be produced artificially by electricity, and animals exposed to artificial ultra-violet irradiation have been proved to manufacture the vitamin within their own bodies. This fact underlies the beneficial effects of artificial 'sun-ray' treatment.

Vitamin E is present in many plants, especially the leaves, such as cabbage and French beans, and in wheat. It is also present in eggs and other animal products. This vitamin has the effect of helping animals to maintain their fertility ; that is, if the diet of an animal be deficient in this vitamin, it becomes sterile ; in other words, it cannot produce young.

There are other vitamins already discovered.

The foregoing brief account of the vitamins is sufficient to show how important they are to animal, especially human, life. This importance is realised to such an extent now, that there are many scientific workers, all over the world, who are examining the nature and the effects of vitamins. Until comparatively recently, nothing whatever was known of their chemical nature. Now we know a certain amount. For example, the chemical nature of vitamin C is well known. It is of an organic acid nature. Vitamin D can now be obtained in a pure crystalline form. It is supplied in this pure form by the British Drug Houses Ltd., under the name 'Calciferol.' This compound is

not prepared from plant products, but by ultra-violet light irradiation of a chemically prepared substance called 'Ergosterol.'

Grape fruit and orange production throughout the world has increased tenfold in the past forty years. More than 6,000,000 new grape fruit and lemon trees were planted in Texas alone in 1932. This has been due to their increased popularity as a dessert and, more recently, a fuller realisation of their dietetic value, especially from the point of view of the vitamins they contain.

It is clear from our brief survey of vitamins, so far as they are understood to-day, that, without being fussy about it, one should always aim at a varied diet with as much fresh food, especially vegetables and fruit, as possible. Uncooked foods of this sort are very desirable so long as they are wholesome and palatable. It is interesting to note what vitamins are consumed in normal meals. Vitamin A (growth-promoting and prevents eye diseases) is present in cheese, butter, liver, cabbage, spinach, egg yolk; vitamin B (prevents beriberi, etc.) is present in tomatoes, peas, asparagus, etc.; vitamin C (prevents scurvy, etc.) is present in lemons, oranges, carrots, apples, cabbages, etc.; vitamin D (prevents rickets, etc.) is present in cod-liver oil, etc.; vitamin E (prevents sterility) is present in cabbages, wheat, etc.; vitamin G (prevents pellagra, etc.) is present in eggs, milk, lean meat, etc.

These highly important chemical substances are of interest to botanists since they are present to such a considerable extent in certain plant tissues. Also, until a much greater advance has been made in the study of vitamins, when it is possible that the most important of them may be manufactured artificially as some already are, we, and other animals, will have to depend upon plants in our diet for the necessary supply of vitamins.

How vitamins are manufactured by plants must remain a problem for some time to come, for little work has been done on this subject so far.

CHAPTER XVIII

THE FLOWER

THE flower is one of the most essential organs of the most advanced plants. The reason that the flower is so important is that it is the usual mechanism whereby the plant reproduces itself. It has already been seen in Chap. III that the flower is so constituted that it can produce seeds. Inside each seed is a young plant. Since this young plant is not yet developed it is said to be **embryonic**, and is sometimes therefore called an **embryo**. Thus the seed contains the embryo of a new plant.

Reproduction by means of seeds is totally different from vegetative reproduction. In the latter, the new plant is just simply developed from certain tissues of the old one. These tissues are formed by the simple division of cells in the old tissues, thus producing the new growth which finally ends in the production of a new plant. On the other hand, seeds bring in a new conception altogether. That is the question of **sex**.

Sexual Reproduction

Seeds are produced by a process of sex and, therefore, reproduction by means of seeds is called **sexual reproduction**.

Fundamentally, there is no real difference between plants and the lowest and highest animals, including man, in their method of sexual reproduction.

The process involves two important cells. When either the plant or the animal is about to reproduce itself sexually, it usually produces one special cell for the purpose. This cell is then capable of dividing a large number of times, thus producing a new tissue, from which the new young plant or animal is produced. This special cell is called a **gamete**. Yet, as has already been stated, two cells are required for sexual reproduction.

This is because one gamete cannot divide and thus develop into a new organism without an impetus or *stimulus* being given to it by another gamete. These two gametes are by no means alike. The gamete which is capable of dividing, provided it is given a start by the other gamete, is called the **female gamete, egg,** or **ovum.** The other gamete, which attacks the egg and forces it to start dividing, is called the **male gamete** or **sperm.**

In forcing the egg to divide and produce an embryo, the sperm actually enters it. Thus there are two special cells called gametes showing a curious phenomenon in that the one cell (sperm) actually enters the other cell (egg). This uniting of the two cells is called **fusion.** The sperm fuses with the egg, and, once inside the egg cell, the nuclei of the two gametes fuse in their turn.

This is the process underlying the sexual reproduction of all plants and animals. It is true that the various mechanisms, whereby sexual reproduction is brought about, vary ; also, the gametes of different plants and animals vary in size and shape ; but the whole process is fundamentally the same. The female egg is capable of dividing and producing a completely new plant or animal, whichever the case might be ; but it is not able to do this until the male sperm has fused with it and given it the impetus to start dividing. This process of the fusion of the gametes to produce a new young individual is called **fertilisation,** and the sperm is said to fertilise the egg.

Hermaphrodite and Unisexual Flowers

In flowering plants, the organ which produces both the eggs and the sperms is the flower ; hence the great importance of the flower.

Many plants and many animals are capable of producing both eggs and sperms in the one organism. For example, in the case of the buttercup, both eggs and sperms are produced in the same flower ; the same applies to the majority of familiar flowers, such as the wallflower (*Cheiranthus*), tulip (*Tulipa*), pea (*Pisum*), violet (*Viola*) and a host of others. In animals this production of both male and female gametes on the same organism is not so

common. It is present in some animals, however ; for example, the common earthworm. In such cases as these, where the same organism produces both kinds of gametes, the plant or animal in question is said to be **hermaphrodite.**

In the other cases the male gametes are produced in one organism, whereas the female gamete is produced in a totally different organism. This is more common in animals than in plants. For example, in the human being, one organism produces the male gametes and is therefore the male organism, or man ; whereas a different organism produces the female gametes and is therefore the female organism, or woman. This is widespread in animals such as horses, cattle, birds, reptiles, frogs, fishes and so forth. Such living things which have only one of the sexes represented in any one individual are said to be **unisexual.**

In plants, unisexuality is not by any means so common. Nevertheless, there are unisexual flowers. The unisexual flower is that type of flower which can produce either eggs or sperms, but not both. Unisexual flowers are again subdivided, because in certain plants both male unisexual and female unisexual flowers grow on one and the same plant, whereas in other cases the female flower grows on one plant but the male flower grows on another plant. Those plants which bear both types of unisexual flowers are said to be **monœcious.** Examples of monœcious plants are the oak (*Quercus*), hazel (*Corylus*), sycamore (*Acer*) and coltsfoot (*Tussilago*). Plants in which the two types of flowers are borne on different plants are said to be **diœcious.** Examples of these are the willow (*Salix*), poplar (*Populus*) and hop (*Humulus*).

There is a great number of advantages in sexual reproduction which vegetative reproduction cannot give. In the case of vegetative reproduction, for example, the potato tuber or the bramble stolon, the young new plants cannot be produced very far removed from their parents unless an artificial agency, like man, steps in and helps. On the other hand, seeds which contain the sexually produced embryos are capable of being carried far away from the parent plant, as will be seen later on in this chapter. This is of great advantage, for whereas those plants

which reproduce themselves vegetatively soon begin to overcrowd themselves, the sexually reproduced plants can, by means of their seeds, be distributed far and wide.

The Inflorescence

Flowers vary considerably, but, since they conform to certain rules, it is proposed to examine one of the simpler types and periodically compare this with the more complex.

One of the simplest types of flower is that of the buttercup (*Ranunculus*).

Each flower of the buttercup is borne separately. It is therefore said to be **solitary** (Fig. 72), to distinguish it from many other kinds of flowers which are not borne separately but in groups of several. A cluster of flowers is called an **inflorescence.**

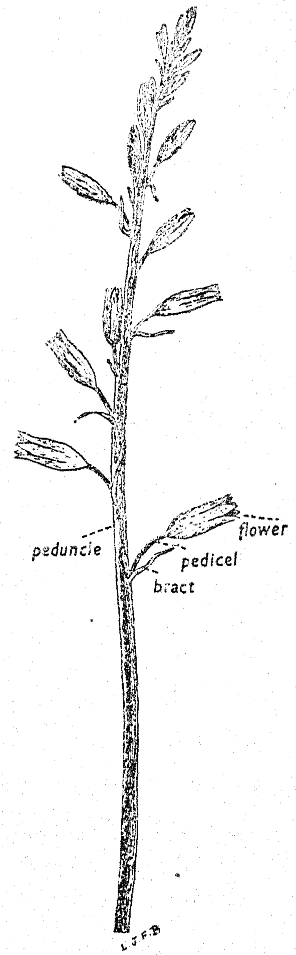


FIG. 231. INFLORESCENCE OF THE BLUEBELL.

Inflorescences vary in arrangement and are classified accordingly. For example, the bluebell and the cultivated hyacinth bear their flowers in inflorescences, each of which may be composed of anything from five to a hundred flowers. The main stalk bearing the complete inflorescence is called the **peduncle.** In this case it is a strong upright stem, just as it is in the case of the delphinium, foxglove, cowslip, etc. Each separate flower is joined on to the peduncle by a short stem called the **pedicel.** Seldom does the pedicel come off abruptly from the peduncle.

As has already been seen, the flower itself may be a very modified branch shoot. Now, branch shoots which develop from lateral buds on a stem are scarcely ever given off by the stem, naked. They are usually given off from the axil of a leaf. If, therefore, the flower is a branch shoot, it would naturally be expected that its pedicel joins the peduncle in the axil of a leaf. This actually is the case, though the leaf, from the axil of which the flower pedicel arises, is clearly not a foliage leaf. It is modified into a small, inconspicuous, tissue-like structure called a **bract** (Fig. 231).

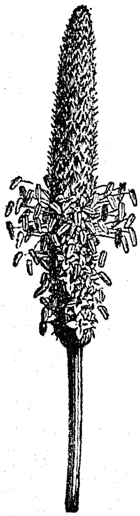


FIG. 232. INFLORESCENCE OF THE PLANTAIN (SPIKE).

In the case of the wild hyacinth or bluebell the inflorescence is very simple, being composed of a single, straight peduncle bearing a series of bracts, from the axils of which pedicels arise, each bearing a flower. The whole is more or less pyramidal in shape, since the oldest flowers, that is, the flowers which open first, are at the bottom of the inflorescence and then the flowers are younger and younger going towards the top. This type of inflorescence is called a **raceme**.

A type of inflorescence similar to the raceme is the **spike**. This differs only in that the flowers are borne directly on the peduncle, that is, they have no pedicels. This type is represented in plantain (Fig. 232).

In another type of inflorescence, the axils of the bracts, instead of giving off pedicels, give off branches of the peduncle. These branch peduncles themselves bear bracts, in the axils of which pedicels are produced. The final structure therefore is a peduncle bearing branch peduncles, each of which is a raceme. This ‘raceme of racemes’ is called a **panicle**. The panicle is characteristic of the *Yucca*, a plant commonly cultivated in parks in the south of England, which bears long, spiked, deep green leaves (Fig. 233).

In a type of inflorescence closely related to the raceme it will be noticed that the length of the pedicels gets longer and longer from the top downwards. That is, the older the flower,

the longer the pedicel. The result is that the inflorescence, instead of being pyramidal in shape, is circular and flat, viewed from above, since, owing to the different lengths of the pedicels, all the flowers, in spite of the fact that they are borne at different levels on the peduncle, are themselves all on a level with each

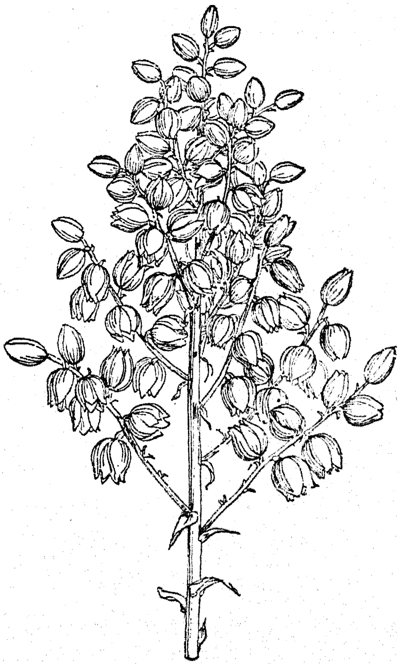


FIG. 233. INFLORESCENCE OF *Yucca* (PANICLE)
(*After A. F. W. Schimper.*)

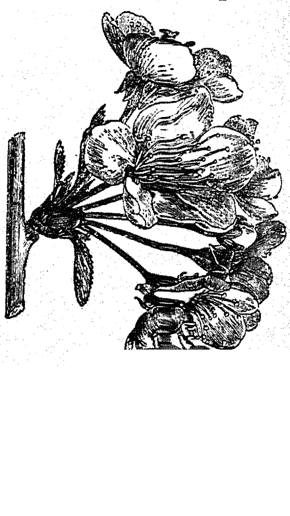
other. This is well seen in the candytuft (*Iberis*). This type of inflorescence is called a **corymb** (Fig. 234).

The same effect is obtained by another type of inflorescence in that all the flowers are on the same horizontal plane, but this type differs from the corymb since all the pedicels are given off from the same level on the peduncle, that is, the top, instead of at different levels. This type of inflorescence is called an **umbel** and is characteristic of the cherry (*Prunus cerasus*) (Fig. 235).

In many plants the umbel is more complicated. It resembles the simple umbel in that all the branches are given off at the same level; but here the branches are not single pedicels, but branches of the peduncle, and each one of these branches in its turn gives off a collection of pedicels at its end. Therefore, the whole inflorescence may be looked upon as being an umbel of umbels or, better still, a **compound umbel.** But the final effect is the same in that all the flowers are on the same level. It is clear that the compound umbel bears the same relation to the simple umbel as the panicle does to the raceme. The compound umbel is very common in Nature, being represented in the parsley (*Petroselinum*), parsnip (*Pastinaca*), carrot (*Daucus*), fool's parsley (*Aethusa*), hemlock (*Conium*), and many tropical flowering plants (Fig. 236).

FIG. 234. INFLORESCENCE OF CANDYTUFT (CORYMB).

In all members of the flowering-plant family called Compositæ, there is a very special kind of inflorescence. This is because the flowers themselves are very peculiar in structure. Many British plants belong to this family, such as the dandelion, sunflower (*Helianthus*), daisy (*Bellis*) (Fig. 237), etc. In a single daisy head, for example, what appear to be single white petals given off in ray-like form from the circumference are, in fact, all single, separate flowers. Each yellow structure, too, hundreds of which form the yellow disc, is a single yellow flower. So here we have a large



number of flowers all borne on the same level on a structure shaped like a bun. This type of inflorescence is called a **capitulum**. The whole inflorescence in the case of the capitulum is supported by a collection of bracts known as an **involucre**.

Other types of inflorescence may be classified as **cymes**. They are more definite than racemose inflorescences because they each end in a flower, and the production of a flower at the end of a shoot prevents further growth in that direction. On the other hand, a raceme does not end in a flower.

There are several types of cymes, but in each case, since the inflorescence terminates in a flower, any further development must take place through a branch. Cymes may be divided into two groups, namely, one-branched, commonly called **monochasium**, and two-branched, or **dichasium**.

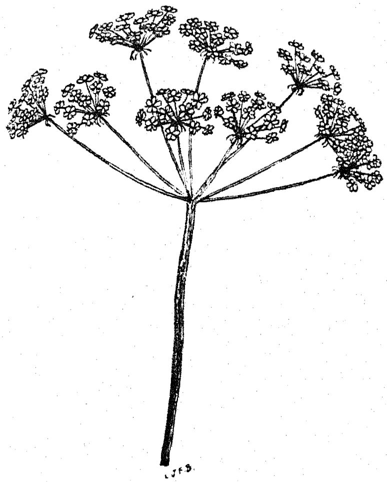


FIG. 236. INFLORESCENCE OF FOOL'S PARSLEY (COMPOUND UMBEL).

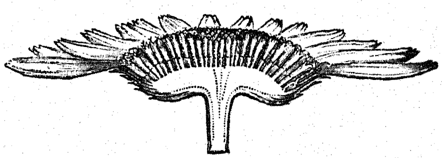


FIG. 237. INFLORESCENCE OF DAISY (CAPITULUM) CUT IN HALF.
(*After Figuier.*)

The former may be divided into two types: (*a*) in which the new branches invariably come off on the same side of the parent stem; (*b*) in which the new branches come off alternate sides of the parent branches.

A typical example of a dichasium is the mouse-ear chickweed. These various types of inflorescences are understood

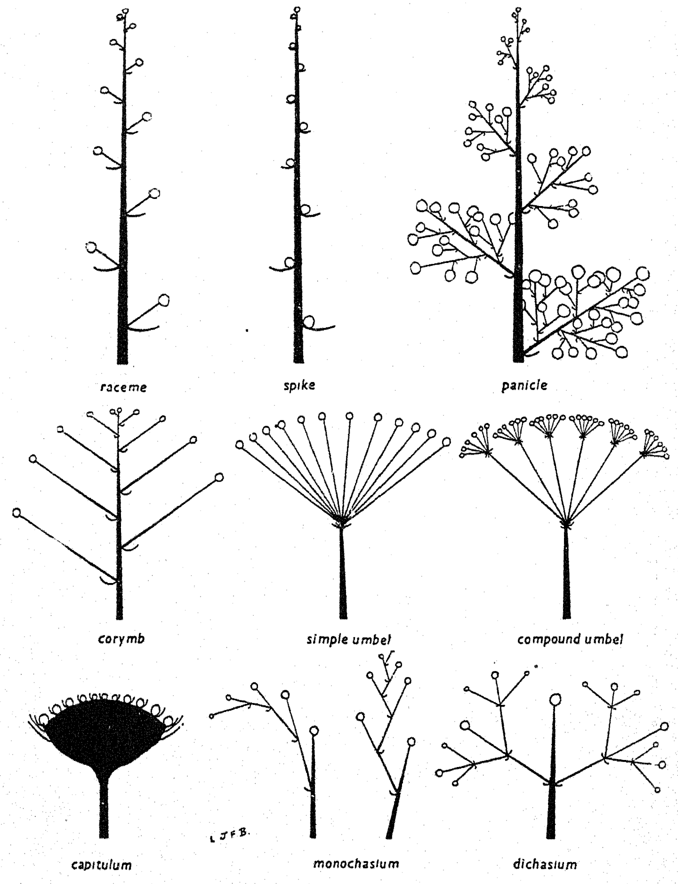


FIG. 238. DIAGRAMMATIC REPRESENTATION OF VARIOUS TYPES OF INFLORESCENCES.

better by reference to their diagrammatic representation in Fig. 238.

The Flower

In view of the enormous variety of flowers in the plant kingdom, no amount of study concerning them from books will help very much in understanding their structure. By far the best method is to gather as many types of flowers, either from the garden or, better still, from the fields and meadows, and to study the floral structure from the real object. When studying flowers in this way, one should always draw them and their various parts separately and, wherever possible, write a description of what is seen.

There are two chief ways of studying the structure of flowers. One is to examine the flower as a whole, then dissect it by removing each organ separately. By this means, however, one often loses the chance to examine the relative positions of the various organs. The second method is better with regard to this, for it involves cutting the flower by means of a sharp knife or pencil, longitudinally down through the centre, then examining the cut half. In this way, all the various organs can be examined with special relation to their position within the flower.

A simple type of flower to examine first is that of the buttercup (*Ranunculus*). In it there are four sets of different organs, all borne upon a swollen structure. This structure is really the swollen end of the stem, and since it bears all the floral organs it is called the **receptacle** (Fig. 239).

Passing from the outside of the flower towards the centre, the four sets of organs may clearly be distinguished. All the organs are arranged around the receptacle in definite groups called **whorls.**

The outermost whorl of organs is composed of five green, boat-shaped organs, each of which is called the **sepal.** The complete whorl of sepals is collectively known as the **calyx.** The function of the sepals is not a very important one ; in fact many other flowers have no sepals at all. The main function of the sepals is that of protection of the more delicate and much more important floral organs nearer the centre of the flower. In the case of the buttercup, for example, when the flower is young and unopened, the sepals, being on the outside, surround the inner

structures and protect them from rain, cold, etc. When the flower finally opens, the sepals help to hold the rest of the floral whorls together. In some flowers, however, the function of the sepals comes to an end when the flower-bud opens. This is demonstrated in the case of the poppy (*Papaver*) flower. Here

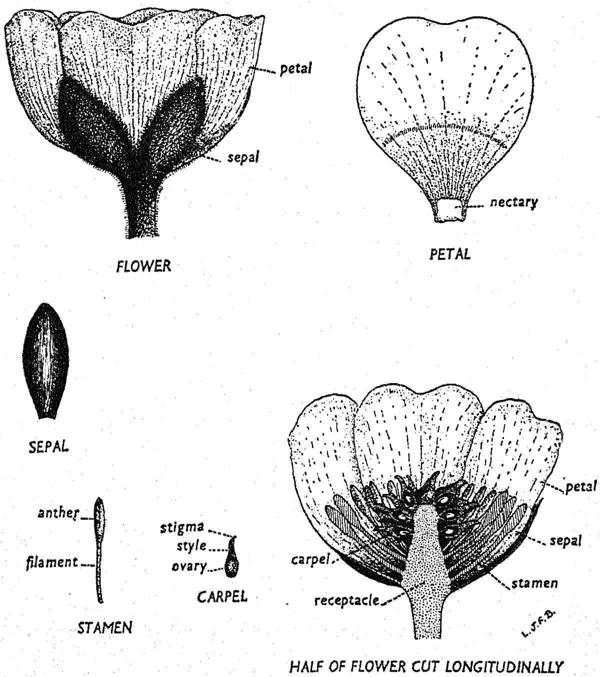


FIG. 239. THE BUTTERCUP FLOWER.

there are two sepals. They form a splendid protective covering when the poppy flower is still in bud ; but when the flower is opened the sepals soon fall off. The result is that the large red whorl of organs, called the petals, have little means of support, with the result that they are soon blown off by the wind. That is why poppy flowers soon 'drop' when they are gathered.

In the buttercup, the next inner whorl to the calyx is the corolla. This is composed of usually five bright yellow, heart-

shaped **petals**, though this number varies slightly. At the base of each petal is a small sac which contains a sweet juice called **nectar**. Therefore the sac is called a **nectary**. Insects visit flowers chiefly to collect this nectar, and from it they make honey. The petals alternate in their position with the sepals. That is, between the five sepals there must be five spaces ; the petals are opposite these spaces and not opposite the sepals themselves.

Next in order to the petal whorl, passing inwards, comes several whorls of structures, yellow in colour and shaped like Indian clubs. These whorls constitute what is collectively known as the **andrœcium**, but each separate structure is called a **stamen**. The number of stamens in any one buttercup flower is large, and the number varies considerably in different buttercup flowers. This is quite different from the case of, say, the hyacinth, where the number of stamens is constantly six.

The innermost whorls of the buttercup constitute what is called the **gynœcium**. This is again composed of an indefinite number of organs, each shaped more or less like a kidney, with a hooked structure at the upper end. Each organ is called a **carpel**.

The main function of the flower, as has already been seen, is to produce male and female gametes and to allow male and female gametes to fuse together, thus producing the young embryo. It is therefore our business to discover which of the floral organs take part in this method of sexual reproduction.

In the case of the example just considered—the buttercup—there are four sets of organs borne in whorls upon a receptacle. They are sepals, petals, stamens and carpels. Neither the sepals nor the petals have anything to do with the production of gametes. Therefore, as floral organs, they are looked upon as being only of secondary importance. In fact, they are really so unimportant that in many cases of other flowers they are absent altogether. For example, in the unisexual willow, the female flowers have no sepals, petals nor stamens and the male flower has only stamens, and no other whorls.

Although sepals and petals are relatively unimportant, stamens and carpels are of the utmost importance, for it is these

organs which produce the gametes. The stamens are responsible for the production of male gametes, whereas the carpels are responsible for the production of the female gametes. In hermaphrodite flowers, like the buttercup, stamens and carpels are naturally present in each flower. On the other hand, in unisexual flowers, stamens only are present in the male flowers and carpels only in the female flowers.

The botanist **Nehemiah Grew**, in 1676, was the first to suggest that the stamens and carpels are the male and female organs, respectively, of plants. Nevertheless, it was not until 1694 that another botanist, **R. J. Camerarius**, really discovered sex in plants. Although the details were not worked out until about 150 years after this, as will be seen later in the chapter, the great Swedish botanist, **Carl Linnæus**, accepted the work of Camerarius and concluded that the stamens and carpels were so important that he used them as the main basis for classifying the flowering plants (see Chap. XXIV).

If a stamen of the buttercup flower be dissected away from the flower and examined under a lens, it will be seen that it is composed of a fine stalk which swells at the top into a long cylindrical structure. The stalk is called the **filament**, and the swollen head the **anther**. The latter is the more important part, and the stalk serves to convey food materials to it from the plant itself. To get a clear idea of how the stamen performs its important function of the production of male gametes, it is necessary to examine the anther under the microscope. Then it is seen to be, not a solid mass of tissue (at any rate when ripe), but to be composed of four cavities which run throughout its length. When ripe, these cavities are filled with hundreds of spherical bodies called **pollen grains**. Pollen grains are not the male gametes, but the male gametes are produced from them, as will be seen when the process of fertilisation is considered, later. Until then, it will be best, therefore, to leave the structure of the stamen and consider that of the carpel.

Externally, the carpel of the buttercup looks like a tiny green kidney with a small hooked projection at the upper end. The main part is called the **ovary**, and the hooked projection the **style**. At the very tip of the style, the surface is sticky. This por-

tion of the style is therefore called the **stigma**. The ovary is composed of tissue enclosing a cavity.

The ovary, therefore, is really a wall surrounding an enclosed space. This wall is often referred to as the ovary wall. From the base of the wall, an egg-shaped structure is borne on a small stalk and projects into the cavity of the ovary. This egg-shaped structure is very important from the point of view of reproduction. It is called the **ovule** because, when it is ripe, it bears the female gamete, egg, or ovum.

Diversity of Floral Structure

There are, therefore, two most important parts to the flower: the stamen, containing the pollen grains, which is capable of producing the male cells, and the carpel, containing the ovule, which produces the female cell. In the process of reproduction, the next stage is the fusion of the male and female gametes. But fusion cannot take place unless the two gametes are in contact with each other. At the present stage they certainly are not, for the pollen is in the anther and the ovule is in the carpel; and both these organs are some distance away from each other. Therefore, although the next fundamental stage is fusion, there are some mechanical processes necessary before this can take place—processes which will bring the two opposite gametes together.

One of these mechanical stages is the bringing of the pollen into contact with the carpel. This process is called **pollination**. The methods of pollination in flowering plants are manifold, and this is where the secondary organs, the petals, are helpful. So, before considering pollination and what happens after pollination takes place, it would be best to examine some different types of flowers, and see how these types effect the process of pollination.

The various whorls of flowers vary in almost every conceivable way. It is naturally impossible to consider them all, but a few examples will give some idea of the diversity of structure.

Calyx

The calyx shows comparatively little diversity. The number of sepals composing it varies; there are two in the poppy, three

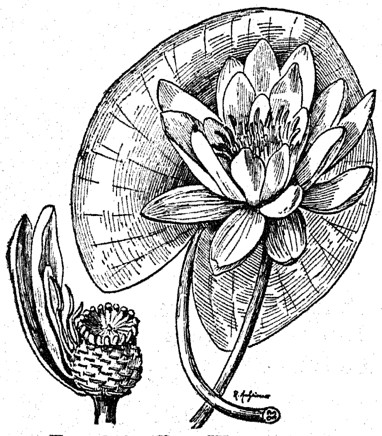


FIG. 240. THE WATER-LILY.
The spiral arrangement of the stamens and petals is shown by their insertions on the ovary to the left (reduced).

in the lesser celandine, four in the wallflower and five in the buttercup. In a few cases, the sepals are numerous, as in the water-lily (*Nymphæa alba*), where they are arranged in a spiral whorl (Fig. 240).

Sometimes the sepals of the calyx are all joined to each other, forming a tube. This is well seen in the case of the primrose (*Primula vulgaris*). There, the calyx forms a definite tube, but it is easy to see that it is really composed of five sepals joined together, by looking at the five long teeth at the top of the calyx tube (Fig. 241).

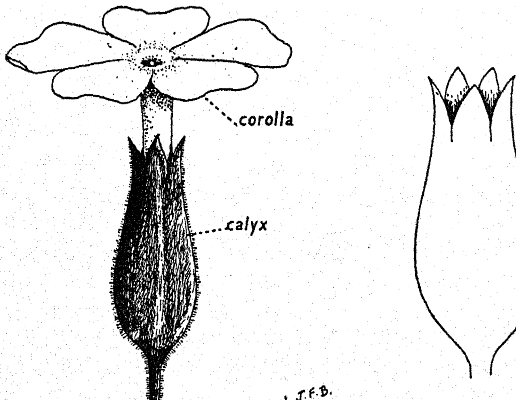


FIG. 241. THE PRIMROSE FLOWER.
On the right, the calyx (enlarged).

Sometimes the calyx, instead of being its normal colour, that is, green, becomes brightly coloured and enlarged and takes on the

function of the petals of the corolla. The calyx in such a case is said to be **petalloid**, and, since it is doing the work of the petals in being bright and attractive, the petals are no longer needed as such. In the marsh marigold (*Caltha palustris*), for example (Fig. 242), what looks like five large yellow petals are really sepals. In this flower and also in the clematis or traveller's joy (*Clematis vitalba*), the petals are entirely absent. In the Christmas rose, the sepals are petalloid, being large and white; yet the petals are not absent but are reduced to small tubular nectaries in their correct position on the flower, that is, between the calyx and the androecium.

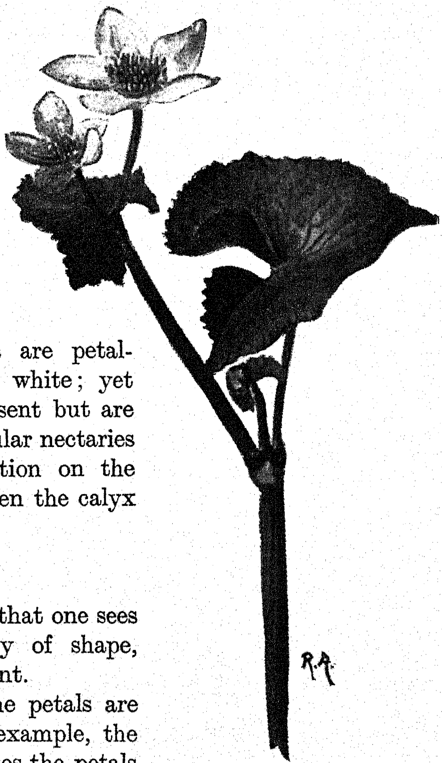


FIG. 242. THE MARSH MARIGOLD (REDUCED).

Corolla

It is in the corolla that one sees the greatest diversity of shape, colour and arrangement.

In some flowers the petals are entirely absent, for example, the willow. In many cases the petals join to form a tube, as in the primrose (Fig. 241). The number of petals, too, varies considerably, even more than in the case of the sepals. For example, the wallflower has four, the pink and the buttercup, five, and many have an indefinite number.

Some flowers are regular in the arrangement of their petals. For example, in the case of the buttercup or the wallflower

(*Cheiranthus Cheiri*), the petals and, indeed, all the floral organs are symmetrical about any axis. That is, it does not matter in what vertical plane one cuts through the flower, the two halves produced are the images of each other. Such regular flowers are said to be **actinomorphic** (Fig. 243).

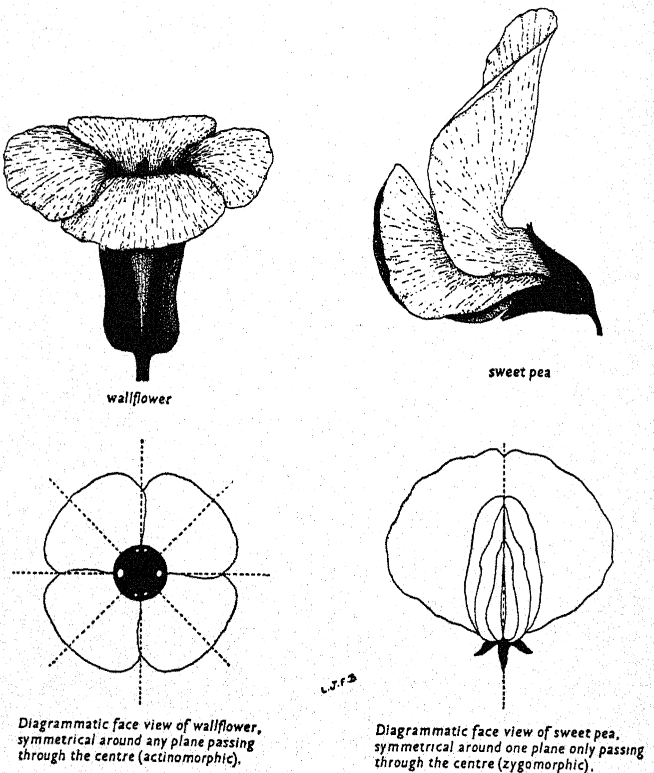


FIG. 243. FLOWER OF THE WALLFLOWER (ACTINOMORPHIC) AND THE SWEET PEA (ZYGOMORPHIC).

On the other hand, many flowers are irregular. In the sweet pea (*Pisum*), for example, there are five petals, but they are not all the same shape. Looking straight towards the inside of the flower, there is one large petal standing

up at the back. It is larger and more spreading than any of the others, and is called the standard. Then, there are two wing-like petals, one on each side of the standard. Each is called a wing. At the bottom are two still smaller petals, facing each other and appearing similar to a ship's keel. The two together are therefore called the keel. In this flower it is quite obvious that there is only one vertical plane through which one could cut the flower in order to produce two symmetrical halves. The plane would pass down the middle of the standard and between the two wings and the two petals forming the keel. Such irregular flowers as these are said to be **zygomorphic** (Fig. 243). Violets (*Viola*) and pansies are also examples of zygomorphic flowers. In the violet, the largest petal has a long spur which projects backwards beyond the floral receptacles. At the bottom of this spur is a nectary.

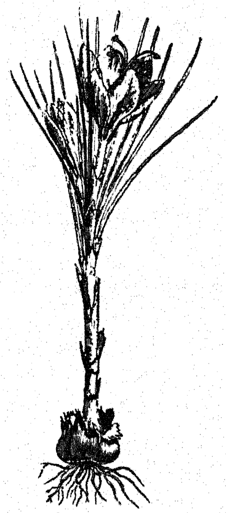


FIG. 244. THE CROCUS. Note that in the flower the perianth is composed of an outer whorl of three and an inner whorl of three segments (reduced). (*After Baillon.*)

In a large number of flowers, it is impossible to tell the difference between the calyx and the corolla. Good examples of this are the tulip, bluebell, crocus, etc. (Fig. 244). The sepals are exactly the same shape and colour as the petals. There are, however, two whorls of these organs, an outer one of three and an inner one of three, which alternate with the three outer ones. Where it is impossible to distinguish between the calyx and corolla, the two sets of organs are grouped together and called the **perianth**.

Stamens

The andrœcium of the flower also shows a great diversity of structure, especially in number of stamens. We have already seen that the number is high and indefinite in the buttercup

(Fig. 239) ; so it is in the poppy and the rose. But in many cases the number is definite. In the deadnettle there are four; wallflower, six; hyacinth, six; and pea, ten. Sometimes the filaments of the stamens differ in length in the same flower; for example, the wallflower has four long stamens and two short ones (Figs. 245 and 246), and the white deadnettle (*Lamium album*), two long and two short.

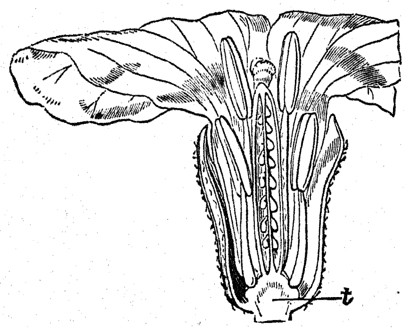


FIG. 245. VERTICAL SECTION THROUGH FLOWER OF WALLFLOWER (ENLARGED). Note two of the long and the two short stamens. *t*, receptacle.

(*After Oliver.*)

In the buttercup, wallflower, etc., the stamens are joined directly on to the receptacle (Figs. 239, 245, and 246). In other cases, however, instead of being fixed to the receptacle, the stamens are joined on to the members of the perianth or on to the petals. In the bluebell, for example, the stamens are joined on to the perianth segments. There is one stamen on each perianth segment, thus giving six stamens in all (Fig. 247). Another example, which is even more curious, is that of the primrose. Here, the stamens, of which there are five, are joined on to the corolla tube some distance up. But the distance varies, in that in some flowers the stamens are about half-way up the tube, and the style of the ovary is long, thus placing the stigma above the stamens; whereas in other flowers, the stamens are fixed at the top of the corolla tube and the style is short, thus placing the stigma below the stamens (Fig. 247).

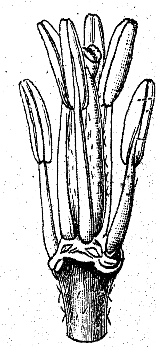


FIG. 246. PISTIL AND STAMENS OF FLOWER OF WALLFLOWER, THE PETALS HAVING BEEN REMOVED.

(*After Oliver.*)

In some flowers, the stamens are joined together as in the dandelion (*Taraxacum*), where there are five joined, thus form-

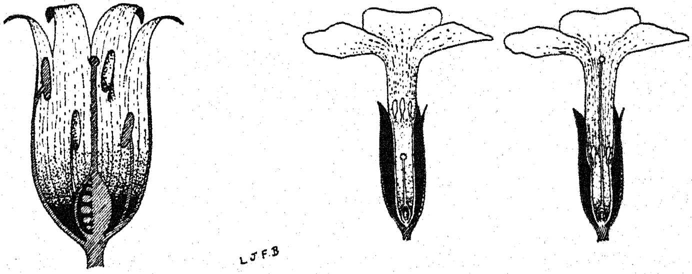


FIG. 247. LONGITUDINAL SECTIONS THROUGH THE FLOWERS OF THE BLUEBELL (LEFT) AND THE TWO TYPES OF PRIMROSE (RIGHT).

ing a tube around the gynœcium (Fig. 248). In others, only some of the stamens are joined, as in the bird's-foot trefoil (*Lotus*

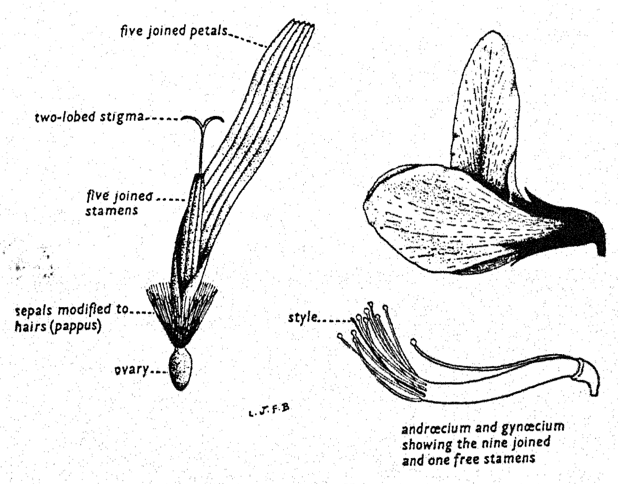


FIG. 248. FLOWERS OF THE DANDELION (LEFT) AND BIRD'S-FOOT TREFOIL (RIGHT)

corniculatus), where there are ten stamens, nine of which are joined and the tenth is free (Fig. 248).

Carpels

The gynœcium shows many interesting forms. One of the simplest is that of the buttercup, where all the carpels are separate. The number, too, is high and indefinite (Fig. 239). In many flowers, on the other hand, the carpels are few and definite in number, and are very often joined to each other.

The methods of joining of the carpels are interesting but complicated. The best way to examine the various types would be first of all to imagine the carpel as an open leaf, bearing its ovules on the margins. It must be remembered, however, that ovules never are borne naked and exposed in this way in Angiosperms ; but, starting with this *hypothetical* case, it is easy to see the various ways in which the ovules could conceivably become enclosed by the carpel, and then see if there are any examples to fit these ways actually existing in the plant kingdom.

The simplest method for the open carpel to enclose its ovules would be to fold in half, thus bringing together its two margins, bearing the ovules. Then, imagine these margins to become joined to each other. Thus should we get one carpel enclosing one vertical line of ovules. This is exactly what we do get in many cases. In the bean (*Vicia Faba*), for example, there is a series of about eight ovules arranged as one would expect them (Fig. 249).

The next method of enclosure would be for two carpels, facing each other, to join at their margins. This would give two carpels forming an ovary with one common cavity into which the ovules would project from two longitudinal rows. This is the case in the gooseberry (*Ribes Grossularia*) (Fig. 249). A variation of this is seen in the tomato (*Solanum lycopersicum*). Here, the margins, four in all, two from each carpel, meet at a common centre. Thus there are two carpels, with two cavities, and a row of ovules projecting into each cavity. In many other cases the same method as that of the gooseberry applies, except that there are three carpels, with a common cavity into which three longitudinal rows of ovules project. This is seen in the violet (*Viola*) (Fig. 249).

Then the variety similar to that of the tomato except that it has three carpels with three cavities, into each of which one row

of carpels project, is also possible ; indeed it is very common amongst flowers. It is seen, for example, in the tulip (*Tulipa*) (Fig. 249). An even more complicated type is seen in the primrose (*Primula vulgaris*) (Fig. 249). Here, there are five carpels joined together but the ovules, instead of forming rows at the

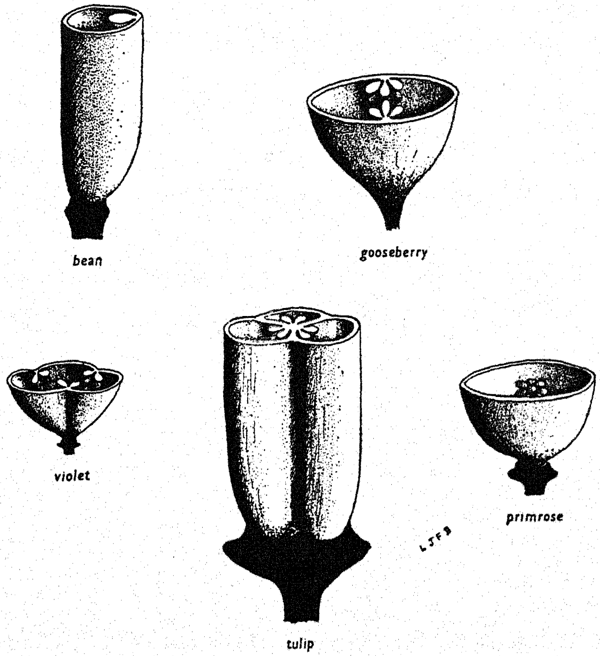


FIG. 249. VARIOUS TYPES OF OVARIES CUT ACROSS TO SHOW THE JOINING OF THE CARPELS.

fused carpellary margins, are borne on a projection from the base of the ovary cavity.

The simple type of gynœcium where the carpels are all free is called **apocarpous**, whereas the ovary which is composed of joined carpels is said to be **syncarpous**.

The arrangement of the ovules within the syncarpous ovary is referred to as **placentation**, because that part of the carpel on which the ovules are borne is called the placenta. In the case of

the gooseberry and violet, where by the method of carpellary fusion the ovules line the ovary wall in longitudinal rows, the placentation is said to be **parietal**. Where the fusion of carpellary margins takes place all together at the centre, as in the tomato and tulip, the placentation is **axile**. The primrose, however, is an example of the ovules being free from the ovary wall. Such placentation is therefore called **free central** (Fig. 250).

In many flowers, the floral receptacle changes its shape so much that the relative position of the various whorls is entirely altered. In the simplest case, such as the buttercup, the gynœcium is at a higher level than all the other whorls ; in other

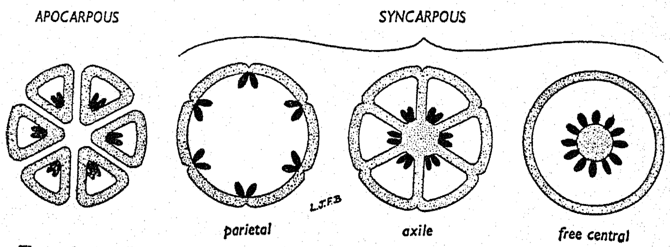


FIG. 250. VARIOUS TYPES OF PLACENTATION SEEN IN TRANSVERSE SECTION.

words, the gynœcium is **superior** to them, whereas they are **inferior** to the gynœcium. Since the other whorls are below the gynœcium, this flower is said to be **hypogynous**. In the opposite extreme, the receptacle becomes cup-shaped, with the result that the whole of the gynœcium is inferior to the rest of the floral whorls, and the ovary wall fuses with the receptacle. This is seen in the pear flower, and is said to be **epigynous**. Then there is a stage intermediate between these two extremes, where the receptacle is only slightly cup-shaped, such as in the case of the lady's mantle. This intermediate type is referred to as **perigynous** (Fig. 251).

Representation of Floral Structure

There are three important ways in which the structure of a flower is illustrated or represented.

One is by means of what is called a **floral formula**. By reference

to a floral formula it is possible to tell (*a*) whether a flower is actinomorphic or zygomorphic; (*b*) whether it has an inferior or a superior ovary; (*c*) the number of sepals, petals, stamens and carpels; (*d*) whether any or all of these are free or joined.

(*a*) Actinomorphy is represented by the sign $\oplus$, and zygomorphy by $\uparrow$; (*b*) an inferior ovary is represented by a line over the sign for the gynœcium, and a superior ovary by a line beneath; (*c*) sepals by *K*, then the number, petals by *C*, then the number, andrœcium by *A*, then number, and gynœcium by *G*, then number. If any of the parts are joined, then brackets are put around the numbers concerned.

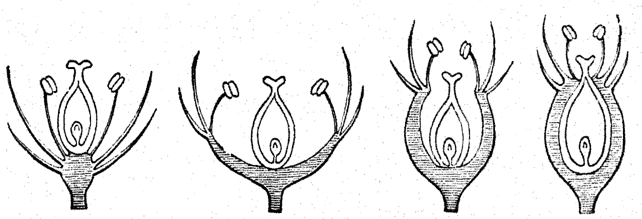


FIG. 251. DIAGRAM OF HYPOGYNOUS (*A*), PERIGYNOUS (*B*, *B'*), AND EPIGYNOUS (*C*) FLOWERS.
(*After Schimper.*)

The following floral formulæ are examples:

buttercup (*Ranunculus acris*): $\oplus\ K5\ C5\ A\,\infty\ \underline{G}\,\infty$
wallflower (*Cheiranthus Cheiri*): $\oplus\ K4\ C4\ A4+2\ \underline{G}(2)$
pea (*Pisum sativum*): $\uparrow K5\ C5\ A(10)\ (\underline{G}2)$

Where there is a perianth and not two separate whorls of sepals and petals, the perianth is represented by *P*. Therefore the floral formula for the tulip is:

$$\oplus\ P3+3\ A3+3\ \underline{G}(3).$$

The second method of representing floral structure is by means of the **longitudinal section**. When drawing this, one must remember that it is not half a flower which is to be represented but just those parts of the flower actually cut by the scalpel (Fig. 253).

The third method of representation is the **floral diagram**. This is really a plan of the flower, with certain portions shown in

section for the sake of clarity. If the sepals, petals or stamens are joined, they are represented as such by small brackets on the

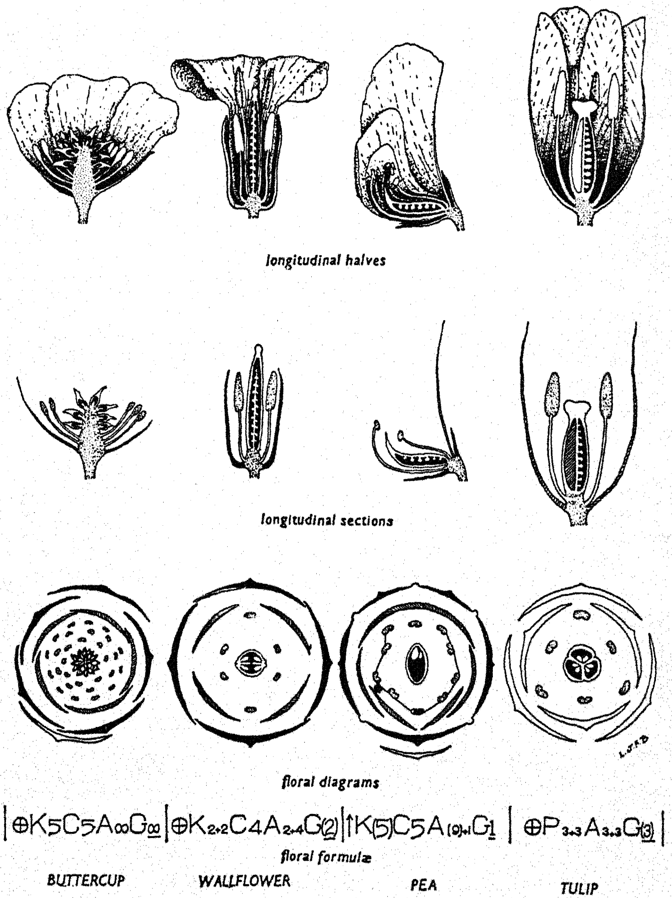


FIG. 252. METHODS OF REPRESENTING FLORAL STRUCTURE.

diagram. This is not necessary in the case of the carpels since they are usually drawn more or less as they really appear in transverse section. A study of the examples shown will give an idea of how to draw floral diagrams (Fig. 252).

Pollination

Having made a brief survey of the diversity of floral structure, we are now in a better position to cast our minds back and follow up the methods of pollination, and then go on to the process of fertilisation which leads to seed production. Pollination is the process whereby the pollen can be brought into such a position that the male gametes can approach the eggs present in the ovules and thus bring about fusion. The position which pollen takes up, in order to do this, is on the stigma of the ovary. The stigma is naturally sticky and thus, if the pollen can be brought into contact with it, the pollen will naturally adhere to it.

The process of pollination can take place in one of two ways. Either the pollen from the stamen of a flower can pass to the stigma of the ovary of the *same* flower ; or the pollen of one flower can pass to the ovary of a *different* flower. The former is called **self-pollination,** and the latter, **cross-pollination.** It will be seen in Chap. XXIV that cross-pollination has many advantages over self-pollination, and that by far the majority of plants use this method. In fact, many flowers are so constructed that they may not only increase their chances of cross-pollination, but also prevent self-pollination.

When the pollen is ripe and thus ready to pollinate a flower, it becomes dry, within the sacs of the anther head. Then the anther becomes ruptured longitudinally and the pollen is thus exposed to the air (Fig. 253).

Self-Pollination

In self-pollinated flowers, the exposed pollen merely drops by virtue of its own weight on to the stigma. The chickweed is a good example of a self-pollinating flower. Although self-pollination is never so desirable to a plant as cross-pollination, some plants, if cross-pollination for some reason or another does not take place, resort to special methods in order to force self-pollination. There are two curious examples of this. In the flower of love-in-a-mist (*Nigella*), a beautiful blue, garden flower, the styles of the carpels are much longer than the

stamens ; so it is impossible for the pollen naturally to fall on the stigma, which is situated at the top of the style. Therefore, when the pollen is ripe, if cross-pollination has not taken place, the styles gradually bend backwards until their stigmas are brought into contact with the exposed pollen on the anther, just like an elephant can bend its trunk backwards to its rider in

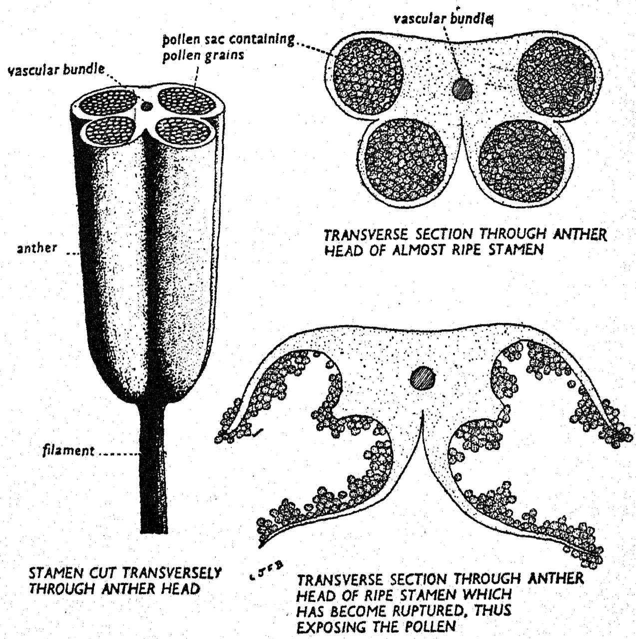


FIG. 253. A TYPICAL STAMEN.

order to take a bun. In the sweet violet, there is an even more efficient method of enforcing self-pollination. In the normal flowers of this beautiful plant, cross-pollination usually takes place. But very often certain flowers are produced which always remain in bud. They never open and are very inconspicuous. Such flowers are said to be cleistogamic. Although they never open, stamens and carpels are present inside them. Thus, when the pollen is ripe and the anther becomes ruptured, the pollen

has no choice other than to fall on the stigma of its own flower.

Cross-pollination

Many plants devise most wonderful mechanisms to ensure cross-pollination; and some go even still further and, by various methods, actually make self-pollination impossible. The simplest obstacle to self-pollination is that in which pollen, when placed on the stigma of the same flower, cannot produce gametes, for some unknown reason. This method, however, is not common. A more common method is to ensure that the stamens of a flower and the stigmas of the same flower ripen at different times; for fertilisation is impossible unless both male and female organs are ripe simultaneously. A good example of this is seen in the plantain (*Plantago lanceolata*). The flowers of this plant are borne in a spike-like inflorescence. In all the flowers, the carpels ripen first. Then the stamens begin to ripen, but from the bottom upwards, with the result that the pollen can never fall on the stigmas (Fig. 232).

Wind Pollination

The methods of cross-pollination are extremely interesting. The simplest method is by wind. This is very common amongst plants with unisexual flowers, such as sycamore (*Acer pseudo-platanus*) and hazel (*Corylus avellana*) (Fig. 254). In the latter, the male flowers, which, of course, produce the pollen, are borne in inflorescences familiarly known as catkins. The female flowers are far less conspicuous. When the pollen is ripe and exposed on the ruptured anthers, it is easily blown off by the wind, since the pollen is so dry. That is why in early spring it is quite a common sight, on windy days, to see clouds of pollen being blown from catkin-bearing hazel bushes. Naturally, the chances of any one pollen grain reaching the stigma of a female flower are very remote in this method. Therefore, thousands of times more pollen is produced than is actually required, since there is a great mortality amongst the pollen grains. This is, therefore, a very wasteful method. Wind pollination is usual among most British trees and grasses.

Insect Pollination

A more efficient method of cross-pollination involves the use of insects, chiefly bees, wasps, butterflies, moths, flies and beetles, as the agents of distribution of the pollen. It is quite clear that these animals can easily collect pollen on their hairy backs and legs, when visiting a flower for its nectar. Then, as the insects pass on to another flower, the pollen collected from the first is

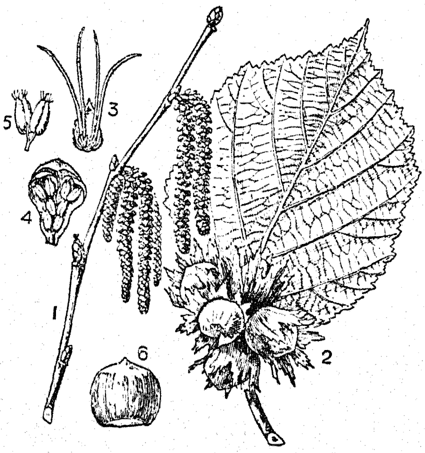


FIG. 254. HAZEL.

1, Branch with male and female catkins; 2, group of fruits; 3, bract with two female flowers (note the long styles); 4, male flower; 5, stamen; 6, fruit removed from cup.

(*After Strasburger.*)

rubbed on to the stigma of the next. This is what happens in its simplest form in the case of the buttercup.

Some flowers, however, are prepared for the insect, and various devices in the flowers make pollination, by means of the insect, certain.

First of all, of course, flowers must attract insects to them. It is scarcely sufficient to have the nectar ready for them, for until the insects actually go to a flower, they cannot be expected to know that nectar is to be found there. Insects are attracted in two chief ways. One is by the bright, attractive colours of the

petals. This is one of the functions of the petals of most flowers. The other way is to produce the delicate perfume so familiar in many flowers. Insects are attracted by this perfume ; in fact, scent attracts insects more surely than bright colours do.

Flies and beetles, sometimes used in cross-pollination, have only short tongues, which are, therefore, useful only to widely open flowers, like the buttercup. Bees and butterflies, on the other hand, have long tongues. The flowers that attract these, therefore, usually have their nectar deeply seated, so that the insect has to push its way right into the flower. Thus, the flower makes sure that the insect touches both anther and stigmas.

A very pretty special adaptation to insect pollination is seen in the highly zygomorphic flower of the sage plant (*Salvia*). In this flower, the stamens ripen before the carpels. There are two stamens. Each stamen is shaped in such a manner as to ensure pollination. The filament is shaped like a T. The anther-head is at the end of one of the branches of the T only, the upper one. The style of the ovary is long and reaches out above the stamens ; so that it is not in the way of the insect. The petals are joined to form a tube, at the base of which is the nectar. The lips of the petals, however, protrude ; and the lower one forces itself outwards to form a landing stage for the insect. When the insect has landed, it forces its head down the corolla tube to get at the nectar. In doing so, it pushes against the lower branch of the T-shaped anther, which then acts as a lever, and the upper branch with its exposed pollen is forced over and touches the insect's back, thus brushing the pollen on it. During this time, the style is above the insect and is not touched. This does not matter, for the time being, since the carpels are not ripe. However, after the insect has gone and taken the pollen away on its back, the stamens die, and then the style ripens and bends forward. By so doing it gets into the direct line of attack of the next insect which comes along. The stigma brushes the back of the insect, and thus collects some of the pollen from its back (Fig. 255).

Sterility of fruit trees is a widespread evil. This is due chiefly to lack of pollination, through the inactivity of insects,

especially humble bees. The Royal Horticultural Society has issued suggestions for dealing with this trouble. For example, bees prefer cherry flowers to those of currants and gooseberries. Therefore these insects will not visit such shrubs if they are in the vicinity of cherry trees. Many insects, too, will visit the

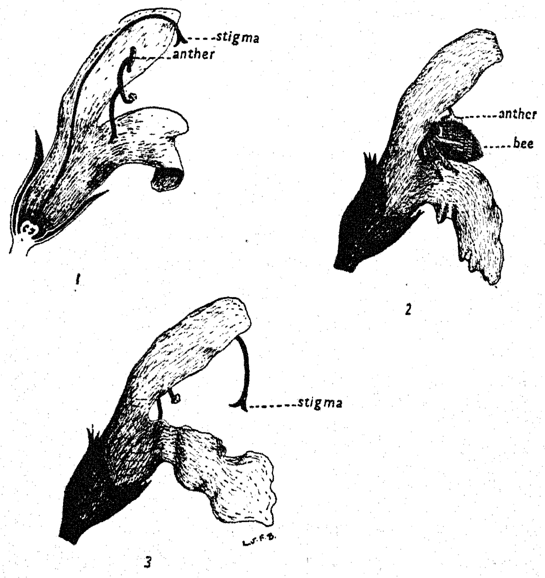


FIG. 255. INSECT POLLINATION IN THE SAGE.

edges, but not the centre of a large orchard. It is therefore suggested that hives of bees should be kept, here and there, amongst the trees of such an orchard.

Fertilisation

Now, having got the pollen on the stigma of the ovary, the next problem is to see how the male gametes from the pollen get to the female gametes of the ovules present inside the ovary. The whole process is looked upon as one of fertilisation and, strange to relate, although the function of the sexual organs was recognised in the seventeenth century, detailed knowledge of the

process dates back to less than a hundred years ago. Fertilisation in plants was first of all described by the Italian naturalist, **G. B. Amici**, in 1823 ; but the process was not really understood until 1846, when much more work was done on it by the English botanist, **Robert Brown.**

It has already been seen that the ovule is usually more or less egg-shaped. When it is ripe and ready for fertilisation, it contains one female gamete, the egg. Its structure, at that stage, is somewhat complex. The ripe ovule is composed of an oval mass of small parenchymatous cells called the **nucellus.** Surrounding this are two layers of cells or coats called **integuments.** At the far end of the ovule, the integuments are pierced by a small pore called the **micropyle** ; thus, at the micropyle the nucellus is exposed. Embedded in the tissue of the nucellus is a large oval sac called the **embryo sac,** for, when fertilisation has taken place, this sac will contain the young embryonic plant. The whole structure of the ovule can be better imagined if it is compared with a plum, although the relative dimensions would be different ; for example, the ovule is microscopic in size, but it will help us to understand this complicated structure. The fleshy part of the plum represents the nucellus. The ovoid stone represents the embryo sac, though the former is thick and solid, whereas the latter is very delicate and contains a fluid. The skin of the plum represents the two layers of integuments. Then imagine the skin of the plum pierced at the end opposite the stalk to expose the flesh, and we have the micropyle.

Inside the embryo sac are several cells, but only two of them are of the utmost importance. The one near the micropylar end of the sac is the female gamete, or egg ; and the one in the centre of the sac is called the **endosperm nucleus.**

Now, the ovule is ready for its egg to be fertilised. The next stage, therefore, is to get the male gamete from the pollen grain on the stigma, to this egg. The egg is passive and does not move. It is the male gamete that has to do the moving. This is done by the pollen grain growing and producing a long tube, called the **pollen tube,** which grows down the style. In order to do this, it must have nourishment, and it gets this from the sugary substances present in the style. The tube continues to grow until

it reaches the cavity of the ovary. Then it passes across this cavity, and the end of the pollen tube forces its way through the micropyle of the ovule into the embryo sac.

Now, the pollen tube contains several nuclei, two of which pass down it and, when the end of the pollen tube gets into the embryo sac, it bursts, with the result that the two cells from the pollen grain are let loose into the embryo sac. One of these cells is the male gamete or sperm. This goes to the female gamete or egg, and fuses with it. Thus the egg has the necessary stimulus to divide and it then begins to do so. The other cell from the pollen grain fuses with the endosperm nucleus, which also begins to divide and produce new tissue.

Sometimes more than one pollen tube begins to grow down through the style; but as soon as one pierces the micropyle, the others die (Fig. 256).

The Seed

Thus fertilisation is completed, and we now have two cells inside the embryo sac capable of dividing and producing new tissue. They both do so. But, in order to carry on, they must have nourishment. They obtain this by absorbing the tissue of the surrounding nucellus. As the fertilised egg divides and divides, producing new tissue, the tissue gradually assumes the shape of a young embryonic plant. It has a young shoot called the **plumule** and a young root called the **radicle.**

But, why is the other cell, the endosperm cell, dividing? This is producing new tissue upon which the young plant may feed later on. This tissue is called **endosperm.**

While all this is going on, the nucellus is being used up, until it finally disappears. The result is, in the end, there is no nucellus left, and the embryo together with its food supply, the endosperm, is left alone in the ovule, surrounded by the integuments. The integuments themselves usually become hardened, so that all that is left now is a young, undeveloped plant or embryo and its food reserve or endosperm, surrounded by a hard coat which is now called the **testa.** This complete structure, which is clearly formed from the ovule after fertilisation, is now called the **seed.**

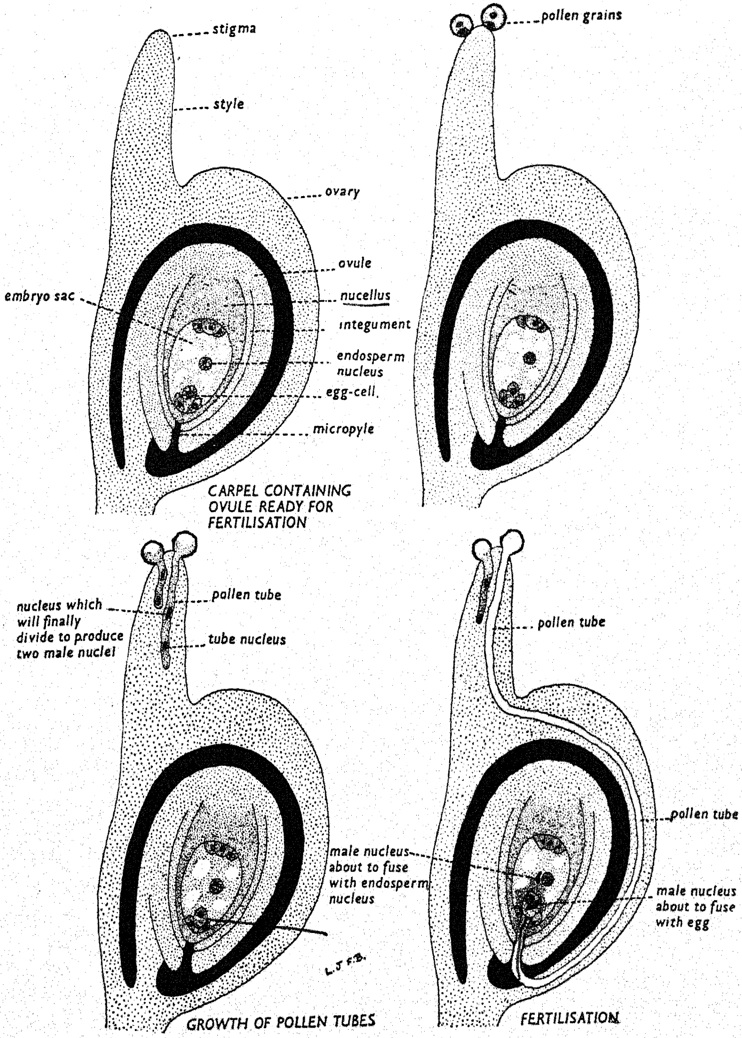


FIG. 256. STAGES IN THE PROCESS OF FERTILISATION.

When the young embryo is fully developed within the seed, the seed may be sown in the ground. In order fully to develop, sometimes the embryo uses up all the endosperm made for its benefit. In this case, the ripe seed contains no endosperm. Such a seed is said to be **non-endospermous** or **exalbuminous.** This is so in the case of the bean, pea, and apple, etc.

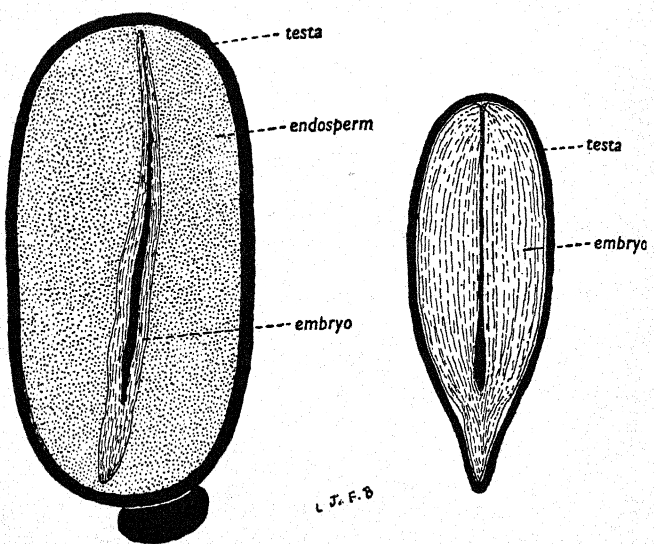


FIG. 257. LONGITUDINAL SECTION THROUGH CASTOR OIL AND APPLE SEEDS.

(Fig. 257). In many other cases, however, the embryo does not use up all the endosperm, so that the ripe seed contains not only the embryo but also a certain amount of endosperm. Thus the young plant still has more food to start with, after the seed is sown, than the young plant which develops from an exalbuminous seed has. Such a seed is said to be **endospermous** or **albuminous.** There are many examples of this type, such as the coco-nut, wheat, castor oil, etc. (Fig. 257). The chemical nature of endosperm varies with the species of plant.

The Fruit

All the time that the ovules are developing into seeds the carpellary or ovary wall is getting stronger and stronger, so that when the seeds are ripe, the ovary wall is strong enough to contain them. Sometimes the ovary wall develops into a thick and hard, or a thick and fleshy, tissue (Chap. XIX.).

The whole ovary, with its developed wall, containing the seeds inside, now forms what is called the fruit. The number of seeds in any one fruit depends not only upon the number of ovules originally in the ovary, but also upon the number of ovules that

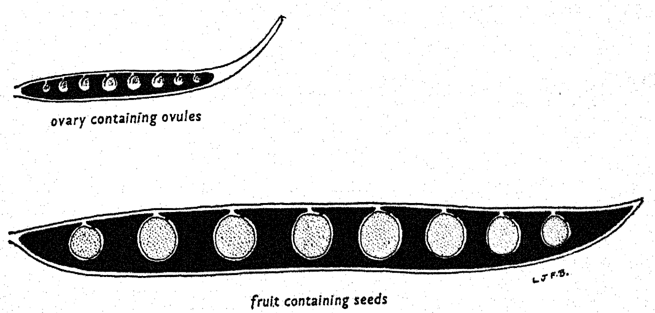


FIG. 258. OVARY AND FRUIT OF THE PEA.

have actually been fertilised. In the carpel of the buttercup there is one ovule, therefore there is one seed in its fruit. In the ovary of the pea, there are about eight ovules; therefore, as is well known, in the fruit, which forms a pod, there are as many seeds, unless some have not been fertilised (Fig. 258).

Naturally a large number of pollen grains get on the stigma, and they all begin to develop pollen tubes; but only the number of tubes corresponding to the number of ovules succeed in penetrating micropyles.

It is very helpful, in order to understand this important, but difficult, process of fertilisation, to name the various parts of the ovary concerned, and see what they all form after fertilisation. After fertilisation, the egg becomes the young embryonic plant; the endosperm nucleus forms the endosperm or food reserve,

unless it is all used up in the development of the embryo ; the nucellus disappears ; the integuments form the testa ; and the micropyle of the ovule remains as a micropyle in the testa of the seed. It can be proved that seeds have a micropyle by soaking them—for example, bean seeds—in water for about twenty-four hours. Then take one out and squeeze it, and the water will be seen to ooze out of the micropyle. All these structures of the ovule together form the seed. The ovary wall becomes the fruit wall, which is called the **pericarp**, and the whole ovary, which contains all these structures, becomes the fruit.

While the fruit is forming, the rest of the floral organs, that is, stamens, petals, and sepals, die away, since they are no longer required. In some cases, however, certain organs persist, usually the sepals. Two examples of such exceptions are very familiar. In the garden pea, the fruit is a pod. The long keel-shaped structure forms the pericarp, which, before fertilisation, formed the ovary wall. Inside are the seeds. But, at the base of the pod, the five sepals are seen still to persist even in the ripest of fruits. In the tomato, the ovary wall, after fertilisation, develops into a bright red fleshy pericarp enclosing the seeds ; but again the sepals persist at the base of this pericarp.

PRACTICAL WORK

(See also Appendix I)

In the study of flowers and their structure, it is important to note that, since plant classification depends to such a great extent upon floral structure, field work is practically essential here.

Flowers should be gathered during walks or botanical excursions, and detailed notes of their habit and habitat should be made. The actual study of the flowers can then be made at home or in the laboratory. It is recommended that a herbarium be started at this stage.

1. Examine the inflorescence of the buttercup. Note how simple it is. Compare this inflorescence with that of the cowslip. Note that in this case, each flower is borne on a short stalk (pedicel), each of which are joined to a main flower-stalk (peduncle). Make drawings of these inflorescences.

2. Collect a large number of plants, with varying types of inflorescences. Make detailed, labelled drawings of these, and group them according to the type of inflorescence they represent.

The chief types of inflorescence to be examined are : spike,

raceme, panicle, corymb, umbel, compound umbel, capitulum, monochasial cyme and dichasial cyme.

When examining these inflorescences, note especially the peduncle, pedicels, and bracts, and their relative positions; do not, at this stage, spend too much time on the details of floral structure.

From the specimens examined and drawings made, describe the various types of inflorescences in flowering plants.

3. Make a detailed examination of a relatively simple flower, for example, the buttercup.

The structure of the flower is best appreciated by making careful drawings as directed. The drawings should be large and in sufficient detail to show the shape and structure of the various organs and their relation to each other.

First make a drawing of the complete flower, noting especially the number, arrangement, shape and colour of each set of organs, namely, sepals, petals, stamens and carpels. Then dissect the flower and make enlarged drawings of a specimen of each organ. Note that the sepal is pale green, boat-shaped, and covered on the outside with hairs. The petals are yellow, larger than the sepals, heart-shaped, and each bears a nectary at its base. Each stamen is divided into two main portions, the filament and the anther-head; whereas the carpels are free and each is composed of an ovary, a style and a stigma.

Half a flower should then be drawn. This shows the relative positions of the various organs of each whorl as they are set upon the receptacle. This should be followed by a true longitudinal section, which indicates only those organs through which the scalpel passes when cutting the flower longitudinally.

A floral diagram should then be drawn, and the whole study completed with a floral formula. In these drawings, colours may be used, especially in the case of the true longitudinal section and the floral diagram. However, it must be realised that, wherever possible, one should avoid using colours, since this usually involves sketchy diagrams unless meticulous care is taken, and much necessary detail is lost.

4. If possible, examine prepared microscope slides of an anther-head in transverse section, and an ovule in transverse and longitudinal sections. Note especially the pollen in the former and the embryo sac containing the egg cell in the latter.

5. Study the diversity of floral structure among flowering plants. Almost any number of types may be chosen, and each of these should then be thoroughly examined, drawn and described as in the case of the buttercup. Points of comparison and contrast should especially be emphasised.

Where time is very limited, good examples to choose would be: buttercup, wallflower, pea, bluebell and primrose.

Flowers showing various adaptations for pollination should also be examined.

CHAPTER XIX

FRUIT AND FRUIT CULTIVATION

THE fruit is the complete structure formed by the ovary after the fertilisation has taken place. It contains the seeds, each one of which is the result of development of an ovule after fertilisation.

The fruits of flowering plants assume various forms, many of which are familiar, since they form articles of diet. In some cases, seeds are distributed naked, but more often they are shed from the fruit. In this case, it is the fruit which is distributed and carries the seed with it. Many fruits are modified in structure in order to enable them to be distributed by some means or other. In some cases, owing to the special structure of the fruit, the seeds become distributed or disseminated over miles of country. The best way to examine this is first of all to study the various types of fruit, and then see how some types are adapted for dispersal.

All fruits can be divided into two general groups, **dry**, and fleshy or **succulent**.

Dry fruits can again be subdivided into two other groups, according to whether they are capable of opening by some mechanism or another, in order to allow the seeds to escape, or not. Those fruits which are capable of opening mechanically are said to **dehisce**, and are therefore described as being dehiscent. Those fruits which are incapable of opening, to allow the escape of seeds, are **indehiscent**.

Dry, Indehiscent Fruits

The indehiscent fruits are the simplest types, and one of the simplest types of all is that of the buttercup. Here, each carpel forms a separate fruit, since the carpels are all separate. After fertilisation, the carpellary wall undergoes no special

change, so that the fruit is simply a single seed surrounded by the carpellary wall, which, after fertilisation, undergoes no change other than that of hardening, in order to protect the young seed inside. This type of fruit is called an **achene**, and it is incapable of opening of its own accord to allow the seed inside to escape. When it is necessary that the seed be sown in the soil therefore, the whole fruit has to be sown, and before the young embryo can begin to develop, the fruit wall, or pericarp, has to rot away. Other examples of achenes are seen in the anemone and the rose. In the latter, the achenes are enclosed in the red receptacle. Achenes are all flattened, dry, tough structures, and are invariably formed from single, free carpels (Fig. 259). Ovaries which are formed from several carpels joined together never form achenes.

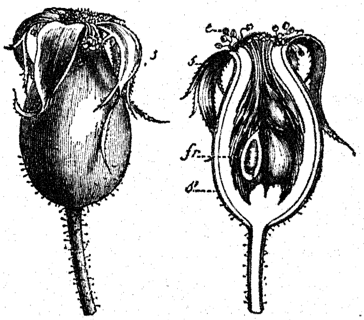


FIG. 259. COLLECTIVE FRUIT OF THE ROSE.

On the right, a longitudinal section, showing a fleshy, hollow axis (s') bearing the achenes ($fr.$)

(*After Duchartre.*)

The flowers of the buttercup and the strawberry plant are very similar in structure. Both contain an indefinite number of free carpels, which are very similar in shape and size. We should naturally, therefore, expect the fruit of the two plants to be similar; yet, on casual observation, they seem very different. The buttercup flower, after fertilisation, leaves a collection of fruit in the form of dry achenes, on a slightly swollen receptacle. What is usually referred to as the strawberry 'fruit,' on the other hand, is a large, red, swollen, juicy structure bearing what appear to be seeds on its surface. Now, actually, the fruit of the strawberry is very similar to that of the buttercup; and this is so, because what is usually referred to as the 'fruit' of the strawberry is not the fruit at all. This is just one of several cases where the fruiterer is wrong when he calls a strawberry a fruit. *It is neither a fruit nor is it a berry.* Another example of such a

mistake in everyday nomenclature is rhubarb (*Rheum officinale*) as used in cooking, which is usually classed as fruit, whereas we already know that this is not the case. It is the petiole of the leaf; and therefore a vegetative structure.

The structure of the strawberry can easily be deduced from that of the buttercup. Imagine the receptacle of the fertilised buttercup swelling to a size about a hundred times that of the normal one. Then imagine it to become red and juicy, and we should then have a large, red, juicy receptacle with the achenes on its surface. That is exactly what we have in the case of the strawberry. The so-called 'fruit' is really a very much swollen receptacle, and the so-called 'seeds' are really fruits in the form of very small achenes. Thus, the familiar red strawberry is really a swollen receptacle bearing many *fruits* on its surface (Fig. 260).

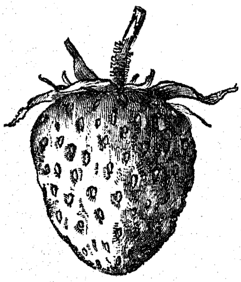


FIG. 260. SUCCULENT RECEPTACLE OF THE STRAWBERRY, BEARING MANY FRUITS (ACHENES). (*After Figuier.*)

The strawberry is cultivated for its luscious, so-called 'fruit' in many parts of the world. The cultivated plant is a variety of the wild strawberry (*Fragaria vesca*), common in hedgerows and on sunny banks.

The strawberry plants require a good, well-manured soil with, in Great Britain, a southern aspect, for the ripening 'fruits' require warmth and light. Plants are seldom reproduced from seeds in cultivation. Runners, the vegetative means of reproduction described in Chap. IV, are more frequently utilised. The runners are usually pegged to the soil at the nodes, thus ensuring the development of the necessary adventitious roots. Often, the runner is led to a pot, and pegged to the soil in the pot. When the young plant has established itself, the runner is severed, and the new young plant allowed to develop in a greenhouse. The name 'strawberry' was given to this plant because, after the flowers have opened, the plants are surrounded with straw so that the 'fruit' shall not become contaminated by contact with the soil, and also to reduce the ravaging effects of

slugs and snails. The use of straw is not so widespread nowadays, for the ' berries ' usually ripen too quickly to warrant it.

The variety of strawberry favoured in Great Britain is called Royal Sovereign. It gives a large, luscious ' fruit.' Strawberry cultivation is more common in the south of England than the north, since the ripening fruit needs plenty of warm sunshine (Fig. 261). Nevertheless, in certain parts of Scotland, especially the Clyde valley, strawberry cultivation is a thriving industry,

FIG. 261. IN A STRAWBERRY FIELD.
(*Photo. A. H. Bastin.*)

supplying the raw materials for the famous jam-making industry of Paisley. About 90 per cent. of the total strawberries consumed in Great Britain are grown in her own strawberry fields. In the south, the main regions of cultivation are around King's Lynn and Spalding in Kent and around Botley, Fareham and Swanwick in Hampshire. Kent usually produces a greater yield than Hampshire. About 800,000 cwt. of strawberries are consumed in Great Britain every year.

The strawberry is attacked by several forms of disease. The chief are the eel-worm disease, caused by an animal which attacks the plant through the roots, and certain fungal

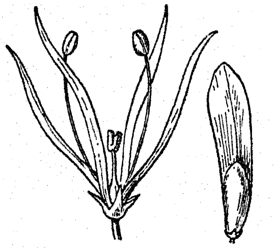


FIG. 262. FLOWER AND FRUIT (SAMARA) OF THE ASH.

diseases which attack it through the leaves. Research on the problems of strawberry diseases is going on at the Long Ashton Fruit Research Station, Bristol, and there is also a special strawberry experimental station at Botley in Hampshire.

The strawberry 'fruit' is composed of about 90 per cent., by weight, of water. Its chief food value lies in its iron content, which helps in the production of healthy blood, and its vitamin C content.

FIG. 263. ASH TWIGS IN AUTUMN, WITH WINGED FRUIT. (*Photo. Henry Irving.*)

Closely related to the achene is the fruit called the **samara**. In this case, also, there is only one seed enclosed, since each fruit is formed from one carpel containing one ovule. The difference

between the achene and the samara is that, whereas the pericarp of the former is formed from the carpellary wall unchanged except that it becomes hardened, in the latter the carpellary wall becomes not only hardened, but also extended at the top into a long, flattened, wing-like structure (Fig. 262). A good example of a samara is seen in the fruit of the ash (*Fraxinus excelsior*), which hangs from the tree in large bunches, after fertilisation (Fig. 263). The reason for the extension of the pericarp into a wing will be examined later. The fruit of the sycamore (*Acer pseudoplatanus*) is also a samara, but in this case very often two

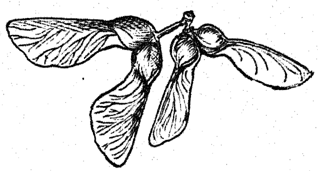


FIG. 264. TWO SYCAMORE FRUITS, EACH CONSISTING OF TWO SAMARAS.

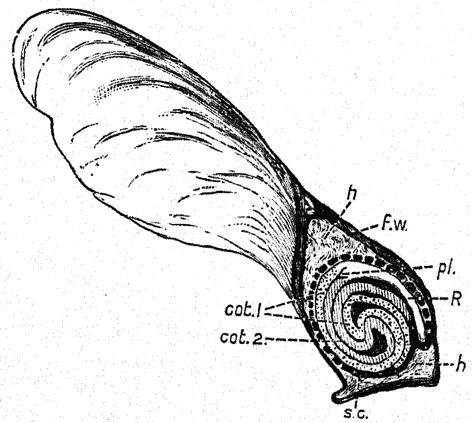


FIG. 265. ONE SYCAMORE SAMARA CUT IN SECTION.
s.c., seed coat, represented by dotted line; *f.w.*, pericarp; *h*, lining of hair; *R*, radicle; *pl.*, plumule; *cot.* 1, *cot.* 2, cotyledons.

and sometimes three samaras fuse slightly at their swollen bases (Figs. 264 and 265).

Another type of fruit closely related to the achene is the nut. In this case, normally there is only one seed present, thus showing

that the ovary was originally formed from one carpel. The pericarp becomes very hard and woody. The term 'nut' is often popularly applied to other types of fruit, such as the coconut and walnut, which are not true nuts at all, as will be seen later. A good example of a true nut is the hazel (*Coryllus avellana*). The shell is the hardened pericarp, and the kernel is the seed. The carpel contains two ovules, but usually only one of these develops into a seed, thus giving one kernel; but sometimes both ovules are fertilised and then we get a nut with two kernels. The nut is situated in a large, green, leafy cup called a **cupule**, which is formed from bracts which persist after fertilisation (Fig. 266).

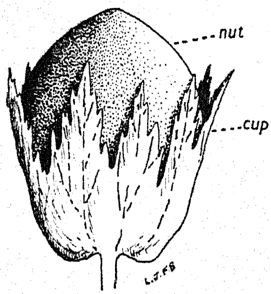


FIG. 266. FRUIT OF THE HAZEL (NUT).

The hazel plant is normally a tree, but very often in Great Britain it is coppiced to form copses and hedges. The hazel nut is seldom cultivated since it grows in such profusion all over the country. There is a variety, however, called the **filbert**, which is a cultivated variety, bearing nuts which are longer and larger. It is cultivated in various parts of the south of England, especially Kent. The plants are usually propagated by suckers, layering and grafting. Several other varieties of the hazel are cultivated in the United States. The hazel nut is used as a food, chiefly for the oils it contains. Many other true nuts, and other fruit erroneously classified as nuts, are used for the same purpose. Also, in many cases, the oils are extracted for commercial purposes, as was seen in Chap. VI.

The **schizocarp** is an interesting type of indehiscent fruit in that it is formed from two or more carpels, and, when fully ripe, it splits into portions, each portion containing one seed. For example, the schizocarp of the mallow (*Malva*) and hollyhock is a round, bun-shaped structure; when ripe, it splits into its one-seeded segments in a manner similar to the manner in which an ordinary round cake is cut.

The geranium shows an even more curious type of schizocarp.

Here, the ovary is composed of five, joined carpels. The style is long and tapering, and even when the fruit is ripe, the style persists as a tall spike (Fig. 267A). Finally, the fruit splits at the base into its five one-sided portions. The central portion of the persistent style remains rigid, but the outer tissues of the style also split from top to bottom into five portions, each portion being joined at the base to one of the one-seeded portions of the fruit. When splitting is complete, each ribbon-like portion of the

FIG. 267. FIELD GERANIUM.

style begins to tear away from the central rigid portion, from the bottom upwards, carrying one of the seed-containing portions with it (Fig. 267B).

Dry, Dehiscent Fruits

One of the simplest kind of dehiscent, or splitting fruit is that called the **follicle.** Examples of the follicle are seen in the marsh marigold (*Caltha palustris*), monkshood (*Aconitum*) (Fig. 268) and larkspur (*Delphinium*). Each follicle is formed from a single, free carpel, containing several ovules. After fertilisation and the complete ripening of the seeds, the fruit or follicle splits along the inner margin, that is the margin which bears the seeds, sometimes called the **ventral suture** as distinguished from the outer margin or **dorsal suture.** The split goes the whole length of the follicle, and thus the seeds are exposed to the air, ready for distribution.

The **legume**, another dehiscent fruit, differs from the follicle in that it splits along both the inside margin (ventral suture) and the outside margin (dorsal suture), and the two halves of the pericarp move apart, thus completely exposing the ripe seeds. The legume, or **pod**, as it is sometimes called, is typical of peas, beans, vetches, etc. (Fig. 269).

Fig. 268. Fruit of Monkshood (Follicles), before and after Dehiscence.

Members of the wallflower family illustrate a curious fruit structure, owing to the presence in the ovary of an exceptional tissue. The ovary is formed by the fusion, along their margins, of two carpels, as in the gooseberry ; but, as distinguished from the latter, between the two fused carpels a wall of tissue is formed, called the **false septum**. This septum persists in the ripened fruit, in which we have, therefore, two cavities, instead of one, separated from each other by the false septum. In the wallflower, when the fruit is ripe, the two parts of the pericarp, each corresponding to one carpellary wall, separate from the false septum, from the bottom upwards, leaving the seeds fixed to the exposed false septum. In a closely related plant, the shepherd's purse, the fruit is similar, except that whereas in the wallflower the fruit is long and flat, in the shepherd's purse it is heart-shaped ; also, when the fruit is ripe, the two halves of the pericarp separate from the false septum downwards. Very similar to the wallflower fruit is that of honesty (*Lunaria biennis*) except that the fruit is flat and oval, with the result that the exposed false septum is large, oval, and like tissue paper. All these types of fruit are classed as **siliquas** (Fig. 270).

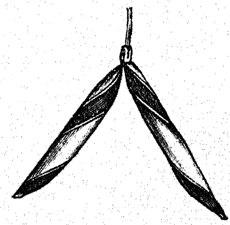


Fig. 269. Fruit of Pea (Legume) dehisced. (*After Lord Avebury.*)

The type of dehiscent fruit which shows the greater number of variations is that called the **capsule**. It is impossible to consider all these variations (Fig. 271) ; but two good examples are

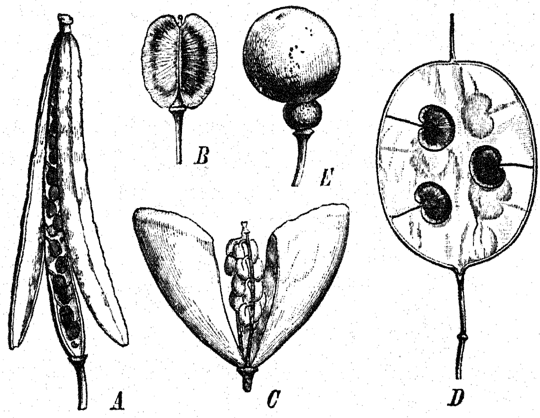


FIG. 270. VARIOUS TYPES OF SILIQUAS.
A, wallflower ; *B*, cress ; *C*, shepherd's purse ; *D*, honesty ; *E*, sea-kale.
(*After Baillon.*)

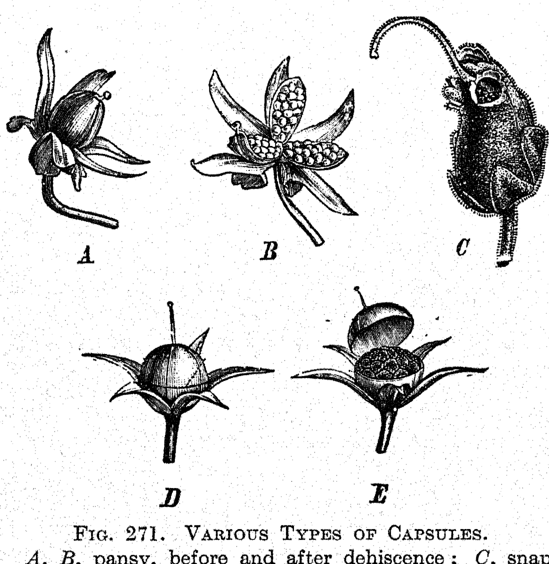


FIG. 271. VARIOUS TYPES OF CAPSULES.
A, *B*, pansy, before and after dehiscence ; *C*, snapdragon ; *D*, *E*, scarlet pimpernel, before and after dehiscence.
(*After Strasburger.*)

seen in the poppy (*Papaver*) and the plantain. In the latter, the capsule is cone-shaped, which, when the seeds are ripe, opens by a transverse split. In the poppy, however, the capsule is of a very unique form (Fig. 272). It is formed from an indefinite number of joined carpels. The placentation is parietal, but the longitudinal parts of the ovary wall, where the carpellary margins fuse (**placenta**), project some distance into the common ovary cavity. The complete capsule is shaped like an inverted cone, with ridges down the outside marking the lines of fusion of the carpellary margins. Ridges also radiate at the top from the centre outwards. The top part of the ovary projects slightly beyond the edge, somewhat like the eaves of a roof. On the side of the capsule, just beneath this projection, a series of perforations is seen, which form complete holes in the ovary wall. There is one hole for each fused carpel. The reason for the perforations will be examined later on.

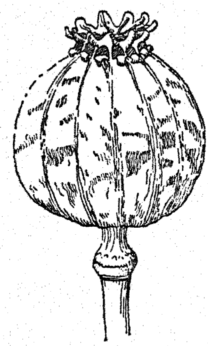


FIG. 272. FRUIT OF POPPY (CAPSULE).

Succulent Fruits

One of the simplest types of fleshy or succulent fruits is the **berry**. In this fruit, the whole pericarp becomes thick and fleshy. This fleshy pericarp is composed sometimes of more than one layer; but all of them are formed from masses of thin-walled tissue, all the cells of which usually contain plenty of food materials, especially sugar or starch.

The Tomato

The tomato is an example of a berry. This fruit is formed by the simple fusion of two carpels. When ripe, the pericarp becomes very thick and juicy, and a viscous fluid is also secreted into the ovary cavities. The pericarp itself is usually divided into a thick, pale red mass of tissue, and an outer, thinner, but tougher, deep red tissue, the skin.

This berry is the source of much food material and vitamins. For ripening, the fruit requires plenty of sunshine; therefore, in

Great Britain, the plant is not a very great success when cultivated outdoors; but, in the greenhouse, the necessary warmth is supplied (Fig. 273).

The tomato is really native to South America. It was brought to Europe at first by the Spaniards, when, for a long time, it was called the 'love apple.' As a vegetable, it has only been popular

FIG. 273. TOMATOES UNDER CULTIVATION.
(*Photo. Sutton Sons.*)

in Great Britain for about seventy years. Now, as the result of cultivation, there are about 150 varieties of this plant. It is a popular plant in market-gardening in the British Empire, the Continent and the United States.

The canning of tomatoes is gradually becoming a thriving industry. In Great Britain, the most extensive areas of tomato cultivation are in the Lea Valley, around Worthing in Sussex, and in the Channel Islands.

The plant is subject to several diseases, the chief ones being

caused either by a fungal parasite or a virus which attacks chiefly the leaves and the fruit.

The Grape

The fruit of the grape (*Vitis vinifera*) is also a berry. It is formed by two joined carpels and the pericarp becomes fleshy. There are two forms of grape used as dessert : the black and the green. As has already been seen, this plant vine is cultivated also for the purpose of wine, champagne and vinegar making. In

FIG. 274. FRUITS OF THE GRAPE (BERRY).
(*Photo. A. H. Bastin.*)

Great Britain, it is usually grown in greenhouses owing to the high temperature required for the good development of the fruit. (Fig. 274). One of the largest grape vines in Great Britain is the famous vine at Hampton Court Palace. In the very south of England, especially in Devonshire and Cornwall, the plant sometimes ripens satisfactorily in the open air.

The so-called currants which are supplied by the grocer in the dried condition, and used in the making of cakes and puddings are not in any way to be confused with the black, red and white currants which are cultivated in gardens and fields in Great Britain. Each type belongs to a totally different family of plants. The dried currant is related to other familiar dried fruits, such

as the raisin, sultana and muscatel. All these are berries, and the plants are closely related to the grape vine.

Dried currants, raisins, etc., are actually dried forms of grapes. They are the fruit of smaller vine plants which are cultivated for the purpose to a very large extent in the Ionian Islands and on the mainland shores of the eastern Mediterranean. They are also cultivated in California in the United States. These small vines are cultivated on the lower slopes of the hills, facing the sun, for they require a higher temperature than the ordinary grape vine does. The latter is often cultivated in the same districts, but further up the slopes of the hills. An interesting operation in connexion with the cultivation of these small vines is that of **ringing**. In this process, small incisions right round the stem are made some distance down the shoot. The incisions go deeply enough to allow the bark, phloem and cambium to be removed. This is done just as flowering is commencing; and by removing a ring of phloem in this way, the route for the transport of foods is blocked (see Chap. XII). Thus, the foods remain in the upper parts of the shoots, and give plentiful supply to the developing berries.

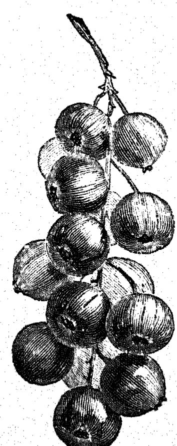


FIG. 275. FRUITS OF THE CURRANT (BERRY). (*After Figuier.*)

The Currant

The true currants (*Ribes*) as cultivated in Great Britain are the fruits of small deciduous shrubs (Fig. 275). They, also, are berries. There are three types, black, white and red. All three types are used chiefly in making puddings, tarts, jams, and other confections. Currant bushes are the subject of many important diseases. Some are fungal, but the most important ones are due to insect parasites, the majority of which attack the unopened buds.

The Banana

The banana is also a berry (*Musa sapientum*). The plant, although it looks like a short tree, is really a herb. The stem is

an underground rhizome, and what looks like the aerial stem is nothing but the petioles of the gigantic leaves, sheathing around each other. The leaves are some of the largest known in Nature. The flowers are borne in long, pendulous inflorescences. They are unisexual, the female flowers being at the base of the

FIG. 276. BANANA IN FRUIT.
(From the Collection, Royal Botanic Gardens, Kew, by permission of the Director.)

peduncle, that is, nearest the 'stem,' and the male flowers nearer the tip of the peduncle. After fertilisation, the female flowers develop the well-known berries, which are formed from three joined carpels. The bunches of bananas, actually the inflorescence after fertilisation, as we see them in the fruiterer's shop, are usually hung upside down, for the berries in Nature grow upright (Fig. 276). More than 200 different forms of banana are cultivated.

Citrus Fruit

Oranges (*Citrus Aurantium*), lemons (*Citrus Medica*), and grape-fruit (*Citrus decumana*) are all closely related plants and their fruits are all berries. If any one of these fruits be cut in transverse section, they will be seen to be composed of six or more fused carpels, and, judging from the position of the seeds, the placentation of the ovary is axile. The pericarp is divided into

FIG. 277. AN ORANGE PLANTATION.

a tough outer skin, which contains many oil glands, and a very fleshy inner portion. All these plants are tropical. Their cultivation forms a great industry since so many fruits are exported. The fruits are cultivated chiefly in California, the West Indies, Brazil, Palestine, along the Mediterranean coast, etc. (Fig. 277). Oranges are used chiefly as dessert, and in making marmalade and certain 'soft' drinks. Lemons are used in cooking, and marmalade and lemonade-making. The grape-fruit is now becoming more popular in Great Britain. All three of these fruits are of great importance, not only for their food value, but also for their high vitamin content (see Chap. XVII).

The cucumber (*Cucumis sativus*) and marrow (*Cucurbita Pepo*) form fruit very similar to the berry, but in this case the fruit is formed from an ovary of three joined carpels, *which is inferior.* It is therefore called a **pepo.**

The Plum, Cherry and Date

Of great commercial importance are many types of the fruit called the **drupe.** Examples of the drupe are plum, cherry, date (*Phœnix dactylifera*), peach (*Prunus Persica*), and three others, commercially called nuts, though botanically they are not : the coco-nut (*Cocos nucifera*), walnut (*Juglans regia*) and almond (*Prunus Amygdalus*).

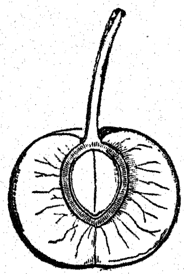


FIG. 278. FRUIT OF CHERRY (DRUPE) CUT IN SECTION.
(*After Figuier.*)

In the drupe, the fruit is formed from either one carpel or from three joined carpels. Whereas in the berry the whole pericarp becomes swollen and fleshy, in the case of the drupe the pericarp swells and becomes divided into several distinct layers. Not all these layers are fleshy, and in some cases, for example, the coco-nut, none of them is. The layers into which the pericarp of the drupe becomes divided are usually three in number : an outer one called the **epicarp,** an inner one called the **endocarp** and a layer between these two called the **mesocarp.**

In the plum and cherry, the fruit is formed from one carpel (Fig. 278). The kernel inside the stone is actually the seed. It is surrounded by a thin papery testa. The epicarp is the tough skin. The mesocarp is the thick, fleshy edible portion, and the endocarp is lignified into a woody structure called the stone.

Plum and cherry cultivation are important industries all over the world. The fruit is used as dessert and in puddings, tarts and jams. The canning and bottling of both fruits are becoming very important industries. These industries are just beginning to develop in Great Britain, although in foreign countries they have been established for some time past. In Great Britain, plum trees are usually cultivated in orchards. The largest areas for cultivation of these fruits are in the west Midlands, Worcestershire

and Gloucestershire. The season for the ripe fruit extends from the beginning of August to the end of September. Before the British season commences, many plums are imported from Spain, France and Belgium.

Plum trees are the subject of many diseases, mainly caused by insect pests. The fruit grower is constantly waging a war against such pests, chiefly by spraying the trees with Bordeaux mixture, or lime and sulphur mixtures, when in leaf, or liming the trunks during the winter, to prevent insect larvæ from climbing them, and thus getting at the leaves and buds upon which they feed.

Planting a fresh orchard is seldom done by means of plum seeds. The usual method of reproduction is the artificial vegetative one of grafting. Cherries are cultivated extensively in Kent. It is interesting to note that, whereas plums are usually cultivated on open soil, cherries are usually grown in grass orchards. Into these orchards sheep are often put to graze, with the result that the soil is richly manured. This is done to a great extent in Kent, resulting in a considerable improvement of the fruit.

Dates, apricots and peaches are tropical forms of drupes. They are cultivated extensively for their food value and shipped abroad. The date and the apricot are used very often as fresh dessert. The peach is, too, but, owing to its high cost of production, it is an expensive form of dessert. The fleshy mesocarps and endocarps of apricots and peaches are canned, and more often reach the housewife in this form. The canning of this fruit is a very extensive industry in the countries where the plants are grown, such as Australia, South Africa and the United States.

The Walnut

The walnut is not so familiar as a drupe, yet, if it is seen growing, there is no doubting its being one, for the walnut familiar as a ' nut ' is only part of the fruit, that is, the seed, enclosed in the woody endocarp. The mesocarp is very fleshy and green, and is surrounded by a thin epicarp. The fruit is formed from two fused carpels in one cavity. As it ripens, the two large seed-leaves or cotyledons, which form the mass of the kernel, become divided by a thin partition, and sometimes even subdivided by partial cross partitions. Towards the end of June, that is, long

before the fruit is ripe, it is often collected and pickled. This is only possible, of course, before the woody endocarp is formed. If the drupe can be pierced easily by a needle, then it is not too ripe for pickling.

The kernel of the ripe nut contains about 18 per cent protein, 16 per cent carbohydrate and a very high percentage of fat. It therefore has a very high food value. The oil is extracted, especially in France, for the manufacture of paints.

The walnut was cultivated before the time of Christ in China, and during the Middle Ages it was a great asset to farmers in Europe. In Germany and France to-day, the trees are cultivated in orchards, and in Czechoslovakia they are grown along the highways and are the property of the village communities.

To-day many walnuts come from China, and the south of Europe, especially Rumania, Italy, France and Spain. In the United States, especially California, the cultivation of the walnut is a quickly developing industry. In Great Britain, walnut cultivation is not so extensive because the variety of walnuts which will grow are not very satisfactory. However, the Ministry of Agriculture and the East Malling Research Station in Kent are busy at present trying to obtain better varieties.

The Almond

The almond is another example of a drupe, though the portion used for food, either raw, salted, or in cake-making, is only the seed. The actual drupe is composed of a pericarp divided into two layers: an outer downy layer, the mesocarp, and an inner reticulated, stony shell. Sometimes this stony shell remains surrounding the seed when the almond is sold, especially with 'mixed nuts' at Christmas time.

The almond is a native of western Asia and northern Africa. It has been known for many hundreds of years, and is mentioned in the Bible. The rod of Aaron was a branch of almond, and even to-day the Jews carry rods of almond in their synagogues on certain of their religious festivals. There are two types of almond: the sweet, which is produced from the pink-flowered almond plant, and the bitter, which is produced from the white-flowered plant. The latter owes its bitterness to the presence of

the cyanogenetic glycoside, amygdalin. Almond seeds contain about 50 per cent oil, and are therefore valuable as a food supply. Almonds are cultivated in various parts of the world, including China, Japan and western Asia, but by far the greatest of the world's supply comes from California.

The Coco-nut

One of the most important drupes, from the commercial point of view, is that of the coco-nut. These drupes are the fruits of the

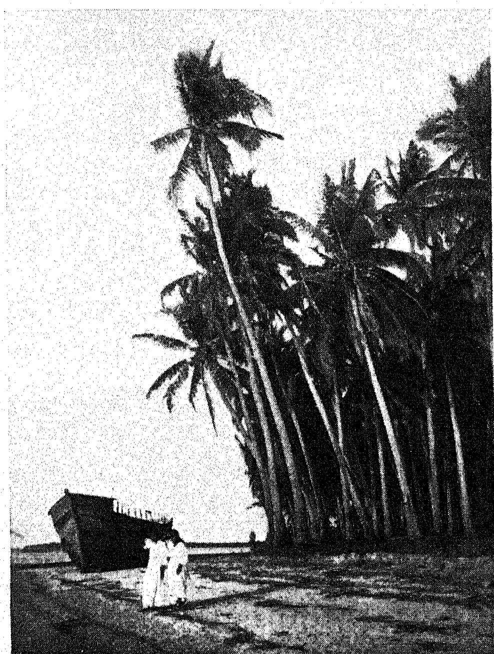


FIG. 279. COCO-NUT PALMS.
(*Photo. Gilchrist.*)

coco-nut palm (Figs. 279 and 280). This is a beautiful tree, attaining a height of 60 to 100 feet. The trunk is bare of leaves, but it terminates in a crown of most beautiful, large leaves, which

are divided into many leaflets. This tree is very widely distributed in tropical countries, sometimes being so dense as to dominate the scenery for miles around. It prefers to live, however, near the seashore. Coco-nut palms are the dominant plants of many parts of India and especially Ceylon, Africa, the East Indies, West Indies, tropical America, and the Pacific Islands, especially the Hawaiian group.

FIG. 280. LOOKING SKYWARD AT A CULTIVATED COCO-NUT PALM.

The drupe itself is composed of a very large pericarp, formed by the fusion of three carpels, but only one of the ovules usually develops into the seed. The pericarp is roughly triangular in cross-section, and is 15 to 20 inches in length (Fig. 281). It is divided into three layers: an outer, thin, tough layer (epicarp), a thicker, very woody endocarp, and a very thick, fibrous mesocarp between. Inside the pericarp is the seed. This is composed of a very thin testa, lined by a thick layer of white endosperm (the edible portion of the 'nut') and, at the base, a very small embryo. The endosperm, as is well known, does not completely fill up the seed, but encloses a large cavity, in which there is a fluid called coco-nut milk. The whole coco-nut fruit is seldom seen in shops. What is usually sold is the seed surrounded by the innermost layer of the pericarp, the endocarp, which is woody. Sometimes a little of the mesocarp is left at one end as a fibrous tuft.

Nearly the whole of the coco-nut plant is commercially useful; it is therefore a very valuable plant (Fig. 282). In some parts the natives depend on it for almost everything. This is especially so in Ceylon, where it is estimated that more than 20,000,000 palms are flourishing.

The endosperm of the coco-nut supplies a good type of food and the 'milk' is a very refreshing drink, especially from unripe fruit. The juice of the unexpanded flowers is sometimes distilled by the natives to make a form of alcoholic drink called 'toddy'. Even the young leaf-bud at the very top of the tree is used as a vegetable, and is sometimes called 'palm cabbage'. The trunk is used as a timber in building and furniture-making, and the leaves are plaited and made into mats, and also for making roofs for the native huts. The shell (endocarp) of the fruit is used for making drinking and other utensils, and the fibrous mesocarp is used in making mats, ropes and string.

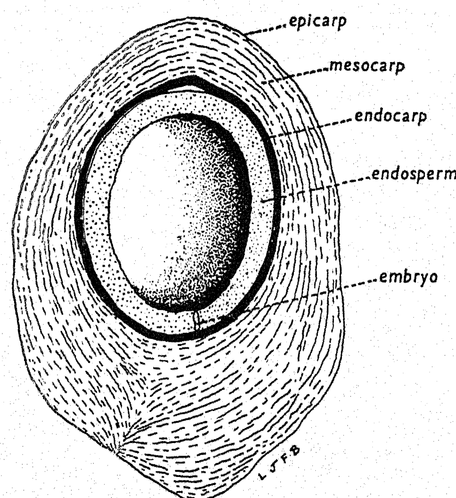


Fig. 281. Longitudinal Section through a Coco-nut Fruit (Drupe).

The fruit of the coco-nut also supplies several products which are exported to other countries. The most important is the

coco-nut oil obtained from the endosperm. This is used in the manufacture of candles, soap, margarine and certain types of brilliantine. The endosperm is extracted from the fruit and cut into small pieces and then dried in the sun. This dried product is called **copra** and forms a valuable export from the tropical countries where the palm grows. The articles already mentioned are then manufactured from the copra.

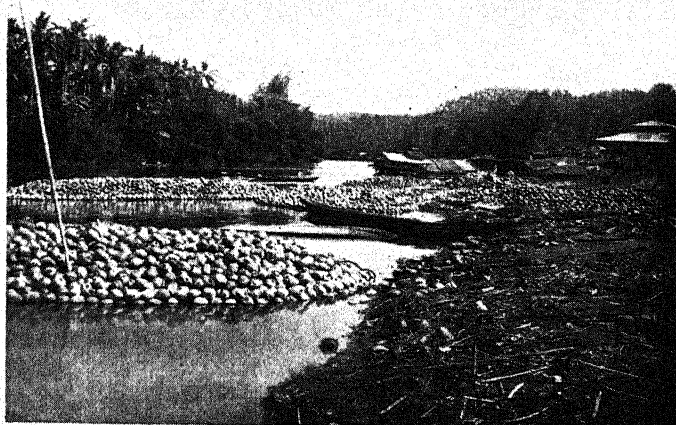


FIG. 282. COCO-NUT RAFTS AT PAGSANJAN.
(*Photo. Bureau of Science, Manila.*)

The fibrous mesocarp is also exported and used in the manufacture of coco-nut mats, cheap matting for passages and lobbies, and brushes. The fresh nuts, exported as a food, come to Great Britain chiefly from the West Indies. As a food, the endosperm is either consumed raw or in the shredded state in cakes and biscuits.

Within the last few years there has been an increase of about 30 per cent in the world acreage under coco-nut palms, bringing the total in 1931 up to 7,000,000 acres. More than half this area is within the British Empire. This increase is due chiefly to the

great demands for copra, from which coco-nut oil is extracted for the soap and margarine industries.

The Apple and Pear

About the most extensively cultivated fruit in Great Britain is the apple (*Pyrus Malus*). This is a cultivated variety of the wild or crab apple. Closely allied to the apple, from the point of view of the structure of its fruit, is the pear (*Pyrus communis*). In both cases, the fruit is formed not only from the fertilised ovary, but also from the receptacle of the flower (Fig. 283). This very special type of fruit is called a **pome**. The flower is epigynous, and the ovary, which is formed from five fused carpels, is also fused to the surrounding receptacle. After fertilisation, this receptacle swells to form the fleshy part of the fruit, and the gynœcium becomes tough, and thus forms the core which also contains the small brown seeds commonly called pips.

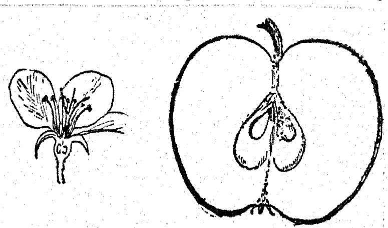


FIG. 283. FLOWER AND FRUIT (POME) OF APPLE, THE LATTER IN SECTION. (*After Strasburger.*)

The apple tree is cultivated solely for its fruits. These are used for food, either as dessert or in cooking, and the very acid varieties are used for the manufacture of the alcoholic drink known as **cider**. In Great Britain the tree is usually cultivated in orchards (Fig. 284). The climate is a handicap to its growth in Scotland, yet there are extensive orchards in Perthshire. Ever since Norman times the greatest apple-growing areas have been in Somerset, Devon, Gloucestershire and Herefordshire. Abroad, apples are also cultivated in small orchards, especially in European countries, but in warmer countries, such as the United States, certain parts of Canada, South Africa, Australia and the West Indies, the trees are grown on extensive farms. Pears are not so much cultivated in Great Britain, since they require a warmer climate. There are, however, extensive orchards of this tree in Middlesex, Hertfordshire, Kent, Norfolk and Worcestershire.

The pear also is used chiefly as a food, but an alcoholic drink called perry is sometimes made from it.

Fruit farming is a great industry throughout the British Empire. Many of the trees are subject to plant and animal pests which cause disease. The better-known methods of dealing with these diseases are those applied as in the case of the plum. The foreign pear is often canned for exporting.

FIG. 284. APPLE, "ONTARIO," SHOWING ARRANGEMENT OF BUSH AND STANDARD TREES IN THE WISLEY TRIAL ORCHARD.

(*By courtesy of the Royal Horticultural Society.*)

In horticultural practice, many new types are obtained by grafting, budding and cuttings. The Ministry of Agriculture, in collaboration with the Royal Horticultural Society, has carried out extensive tests on the hardiness of new varieties obtained in these ways. The trials included apples, pears, plums, cherries, currants, gooseberries, raspberries, blackberries, strawberries and nuts. Yields have been improved, crops made more suitable for marketing and canning, and many have proved more resistant to disease.

The Blackberry

A special type of fruit is that found in the blackberry (*Rubus fruticosus*) and the cultivated types related to it, raspberry and loganberry. In all three cases, the carpels are indefinite and free. After fertilisation, each carpel forms a small drupe, but as ripening proceeds, all the drupes slightly fuse with each other. The fruit is therefore said to be **aggregate**, being formed of an aggregate of drupes (Fig. 285). Blackberries, raspberries and loganberries are all used in Great Britain, either as dessert or in making tarts and jams. The blackberry is a common wild shrub, whereas the shrubs of raspberry and loganberry are usually cultivated.

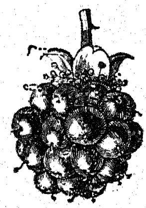


FIG. 285. FRUIT OF BLACKBERRY (AGGREGATE OF DRUPES).

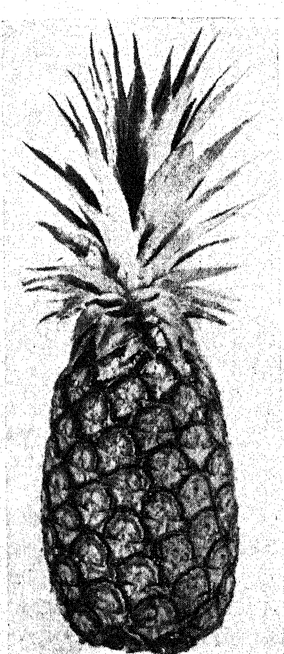


FIG. 286. 'FRUIT' OF THE PINE-APPLE.

(From "Pine-apple Culture," by Hume & Miller, Florida Agricultural Experiment Station.)

The Pine-apple

The last type of so-called 'fruit' which we shall consider is that of the pine-apple (*Ananas sativus*). This is interesting because really it is not a fruit at all, although the fruiterer classifies it as such. The Spaniards, who explored America, gave the pine-apple its name because they thought it looked like a pine cone. It is actually a swollen stem, really a peduncle, together with the real fruit. The stringy nature of the 'fruit' is due to the large masses of xylem in the vascular bundles of this stem (Fig. 286). The swollen stem is a peduncle, because it bears the

flowers and, in the ripened ‘fruit,’ the diamond-shaped areas of the surface mark the remains of the fertilised flowers. Thus the ‘fruit’ is a mixture of swollen stem and swollen fruit all merged into one mass. At the top is a tuft of green foliage leaves. After fertilisation, the fruits themselves become fleshy and fuse with the fleshy stem, thus forming the barrel-shaped ‘fruit.’

The pine-apple plant is a native of tropical America, but it is now cultivated especially in the Hawaiian Islands and in certain parts of the Old World (Fig. 287). The complete plant is a shrub,

FIG. 287. A PINE-APPLE PLANTATION.

and bears the inflorescence which forms the fruit at the top. Below this inflorescence is a large number of long, green foliage leaves.

Advantages of Sexual Reproduction

There are three main reasons why, in general, reproduction, sexually, by means of seeds is more advantageous to a plant than reproduction by vegetative means. First, in the majority of cases, reproduction by means of seeds allows a certain length of time to elapse (from a few weeks to several years) between the two generations of plants, that is, the plants which produce the seeds and the plants which are produced from the seeds. In vegetative

reproduction the new plant can be produced only from a living parent ; whereas, in the case of reproduction by seeds, the new plant need not be produced until long after the parent plant has died. The length of time which elapses naturally depends on how long the seeds can last, before their embryos are allowed to develop into new plants ; and this time varies considerably in different seeds, as will be seen in Chap. XX. Secondly, by means of seeds, the offspring can be distributed far and wide, thus preventing any overcrowding of the plants. The third reason is probably the most important, since it is the reason why sexual reproduction is better than any other means of reproduction in both plants and animals. This reason will be considered in Chap. XXIV.

Dispersal of Seeds and Fruits

Many seeds are so small that they are easily carried away, at any rate a short distance, from the parent plant, by even a slight breeze. Other plants, however, are more efficient in distributing their offspring than that. They have, in many cases, developed definite mechanisms for distributing their seeds.

Seeds are sometimes distributed as such, naked ; but very frequently the seeds are distributed enclosed in their fruit.

The methods whereby seeds and fruits are dispersed may be grouped under four headings : **animal, wind, mechanical,** and **water.**

Animal Dispersal

Many plants disperse their seeds and fruits by means of the agency of animals. The succulent fruit is the simplest type. The fruit of the blackberry, for example, forms a delicious food for birds. The fleshy parts of the drupes are digested by the bird, but the seeds inside are so hard that they pass through the gut of the bird unharmed, and are then ejected with the excreta. In the case of the cherry drupe, the bird often carries it away and eats the fleshy pericarp, but the endocarp (the stone) is so hard that the bird ignores that part of the fruit and drops it. Thus the seed inside is dispersed quite unharmed. Birds are the only animals of any use to the semi-parasitic

mistletoe (*Viscum album*), since its seeds must be carried to the branches of its host trees. In this case, the bird carries away the berries, and, since the berries contain a very sticky juice, the bird, in its attempt to remove the glutinous material from its beak, rubs it against the branch of a tree. In this way is the seed naturally sown.

When such seeds are ready for scattering, but not before, the fruit, etc., usually becomes very conspicuous, in order to attract the useful animals; for example, the cherry drupe is bright red or black, the strawberry receptacle is a bright red, etc.

Certain fruits, instead of becoming attractive to animals in order to be dispersed, develop hooks in order that they may cling

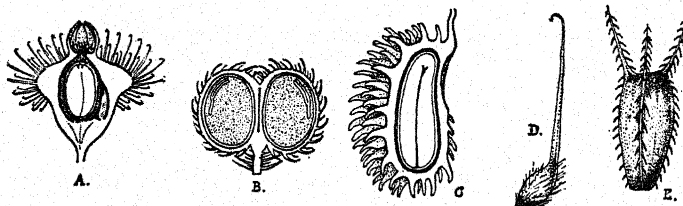


FIG. 288. HOOKED FRUITS ADAPTED TO ANIMAL DISPERSAL.
A, agrimony; *B*, cleavers; *C*, houndstongue; *D*, avens; *E*, bur marigold.
(*After Le Maout.*)

to browsing animals, and thus 'steal a ride.' These hooked fruits are sometimes called **burs**. A very familiar example, which is sometimes quite a nuisance to people walking in the country, is the goose-grass or cleavers (*Galium Aparine*). This plant grows chiefly in hedgerows. The fruit is a more or less spherical schizocarp, and the surface of the pericarp is covered with very small hooks. By means of these hooks, the ripe fruits cling to animals such as rabbits and cows, and they easily become attached to a man's trousers if he walks through the hedgerows where the plant is growing. Thus the fruits are carried some distance before they are dropped.

The burdock (*Arctium Lappa*) is another splendid example of this fruit-dispersal mechanism. The inflorescence of this plant is a capitulum. Surrounding the capitulum is a mass of bracts.

After the fruits are formed, these bracts become dry and hooked. It is easy to see how well this fruit clings, by merely gently tossing it against a person's back, where it sticks. When this fruit becomes attached to a dog, it is almost invariably necessary to cut away the hair in order to remove it. In the wood avens (*Geum urbanum*), and certain cultivated species of *Geum*, the fruit is an achene, but the style does not die away after fertilisation. It remains firm, and becomes hooked at the top, thus forming an organ with which the fruit can cling to a passing animal (Fig. 288).

Wind Dispersal

Dispersal by wind is the cause of most remarkable developments in certain plant fruits. As has already been seen, the samara is an achene in which the pericarp is produced into a long, thin, wing-like structure. This wing is for the express purpose of allowing the fruit to be propelled through the air by means of wind. This is well seen in the fruit of the ash, and especially so in the double samara of the sycamore. The elm fruit is also winged, but the wing in this case is an extension in all directions, in one plane, instead of in one direction only.

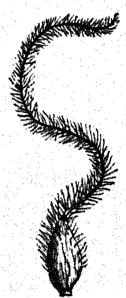


Fig. 289. Fruit (Achene) of Clematis with Hairy Style adapted to Wind Dispersal.

Plumed fruits, that is, fruits which develop hairy outgrowths, are some of the most interesting types which are distributed by wind. In the clematis, traveller's joy, or old man's beard (*Clematis vitalba*), for example, the fruits are a collection of achenes, borne on a receptacle, like those of the buttercup. But in the clematis, the style is very long, and after the fruit has ripened it persists, and then becomes a long, white hair, covered with branch hairs (Fig. 289). Thus, this climbing shrub produces a striking white effect in the hedgerows when its fruits are ripe. The plume on the fruit is its means of dispersal, since the plume helps the fruit to float in the air.

In the flower of the dandelion (*Taraxacum officinale*) the calyx is represented by a ring of white hairs called a **pappus.** The ovary is inferior, and, after fertilisation, the fruit becomes an achene, but the pappus persists, being pushed up on to the top of a very thin stalk, thus forming a beautiful parachute mechanism, by which the fruit travels sometimes for miles through the air (Fig. 290).

FIG. 290. HEAD OF FRUITS OF THE DANDELION.
The pappus is raised above the fruit on an elongated stalk.

In certain thistles the pappus hairs stand out in all directions from the fruit; thus the fruit is made extremely buoyant, and may be seen travelling in parts where there are no thistle plants for miles around, thus showing what great distances such fruit can travel.

The poppy also depends upon wind for the dispersal of its seeds, though in this case the seeds are distributed as such and not enclosed in the fruit, as in the other cases so far considered. It is a curious mechanism, depending upon the perforations in the dry pericarp wall, which have already been mentioned. Inside the ripened capsules, the seeds are dry and loose. The capsule, being at the top of the long stalk, is easily swayed about in the wind, and thus the seeds are shaken out through the perforations. This is similar to shaking pepper out of a pepper box and is therefore called the pepper-box mechanism (Fig. 272).

Wind dispersal is probably the best method whereby plants can be disseminated over large areas.

Mechanical Dispersal

In mechanical methods of seeds dispersal, the fruit itself is responsible for the mechanism. The seeds are shot out, as if from a catapult. Since the mechanism is the fruit itself, it is the naked seeds that are dispersed, and not the fruit. The pods of peas, beans and vetches demonstrate this mechanical method splendidly. When the fruit is ripe and dry, the two halves of the legume or pod begin to shrivel. But the shrivelling takes place at unequal rates in different layers of the pericarp walls. The result is that the two halves first of all separate, and then each of them twists. This takes place so quickly that the action is almost explosive, thus shooting the seeds out for a considerable distance. It is not easy to watch this taking place in the garden pea and bean, since the fruit of these plants are usually gathered before they are ripe. But it is possible in the vetch (*Vicia*). When the pods of this plant are ripe, on a very hot day, their explosive action is easy to see, and also easy to hear, for, standing quietly amongst a growth of vetches, the gentle 'pop,' 'pop' of the exploding fruit cannot be missed.

The splitting of the schizocarp of the geranium and *Pelargonium* already described, also of the meadow cranesbill (*Geranium pratense*), a closely related type, also takes place very quickly on a dry day. So sudden is this splitting that the five fruit portions, each containing a seed, are flung suddenly for some distance.

Water Dispersal

Dispersal of fruit by water is not so common. The best example of this type, however, is that of the coco-nut. The fibrous mesocarp of the fruit contains a large number of air spaces, thus making the whole fruit very buoyant. When the fruit is ripe it falls from the tree, and, since the coco-nut palm grows chiefly along the seashore or along the banks of rivers, the fruit usually falls into water. Then it floats in the water, along the shore, or down the rivers, finally being washed up on to dry land, or caught on the mud, where it develops into a new plant.

The water-lily, in Great Britain, disperses its seed by means of water. The seed of this plant has an extra coat called an aril. This aril is spongy, and in the spaces of the spongy network there is air, thus making the seed buoyant. Thus the seed floats with the stream, but finally the aril becomes saturated with water and therefore loses its buoyancy. Then it sinks, and develops on the bed of the stream.

PRACTICAL WORK

1. By means of a hand lens, examine the collection of carpels of the buttercup, when they have ripened after fertilisation, thus forming a collection of fruit. Each fruit is an achene. Dissect one and find the single seed enclosed. Make drawings of this fruit.

Compare a ripe strawberry with the collection of buttercup fruit and describe how, though both appear so different from each other, they are essentially similar.

2. Examine and draw a bunch of ash fruit. Make a detailed examination of a single fruit and cut a longitudinal section of it, thus exposing the seed. Discuss the manner in which this samara of the ash differs from the achene of the buttercup, giving reasons, especially from the point of view of mechanism of distribution.

Examine a double samara of the sycamore.

3. Draw a hazel nut, partly enclosed in its leafy cup. Examine the nut in detail and expose the seed. Compare this fruit with that of the buttercup.

Examine the schizocarp of the hollyhock and compare this with the other types of dry, indehiscent fruits.

4. Compare and contrast, by means of drawings and written descriptions, the various types of dehiscent fruits.

The follicle of larkspur splits along its ventral suture. It is formed from one carpel composed of one locullus and contains several seeds.

The legume of the pea, on the other hand, is formed from two fused carpels and it finally splits along both margins. When the pea fruit is ripe, note the manner in which both parts of the pericarp twist, thus throwing the seeds some distance from the parent plant.

Various types of siliquas should be examined; for example, wallflower, shepherd's purse, honesty. These fruits are formed from two fused carpels, and are distinguished by the formation of a false septum. Note how they split to expose the seeds.

The capsule shows many variations, some of which should be examined.

5. Many types of succulent fruits are of economic importance, so it is important to examine some of them.

Drawings should be made of the complete fruit, and, where possible, it should be dissected, and longitudinal and transverse sections drawn.

Examples of the following should be studied: berry (gooseberry, currant, tomato, banana, grape, orange); pepo (cucumber); drupe (plum, cherry, date, coco-nut, walnut); pome (apple, pear); aggregate fruits (blackberry, raspberry).

In certain cases, especially the drupe, the pericarp shows a complicated structure, as described in the text. This should be examined and the various layers defined.

6. The mechanisms adopted by seeds and fruits in order to ensure dispersal, make fascinating practical study.

Apart from the fruit already examined, the following are worthy of study: burs of cleavers, burdock, and wood avens; plumed fruit of clematis, dandelion and thistle; splitting schizocarp of geranium; etc.

CHAPTER XX

GERMINATION OF SEEDS

THE seed contains a new plant in embryo. Given suitable conditions, this embryonic plant will gradually develop into an adult. The development of the seed, from the embryo to a newly established plant, is called **germination.**

Structure of Seeds

As has already been seen, the seed is composed of an embryonic plant surrounded by a skin called the testa. In some cases, the testa also encloses an extra food supply called endosperm, and the seed is then referred to as being endospermous or albuminous ; in others, no endosperm is present, in which case the seed is said to be non-endospermous or exalbuminous.

An excellent example of a non-endospermous seed is that of the broad bean (*Vicia Faba*). This seed is kidney-shaped. The testa is tough and a light brown in colour. On one edge of the seed there is a dark, elongated patch known as the **hilum.** At one end of the hilum is the micropyle, which corresponds to the micropyle of the ovule from which the seed was formed after fertilisation. It is not easy to see this micropyle with the naked eye, but its position can be clearly located by gently squeezing a soaked seed, when the water will ooze out through it. At the opposite end of the hilum is a small raised piece of tissue. This marks the remains of the stalk by which the ovule was joined to the carpellary wall, and later, after fertilisation, the stalk by which the seed was joined to the pericarp of the leguminous fruit (Fig. 291).

If the testa be carefully removed by means of a penknife or scalpel, the seed will be seen to be composed of two white, kidney-shaped portions, lying flat against each other. The sur-

faces of these two halves are not joined to each other except at one small region on their edges. Treating this region as a hinge, the two halves can be gently opened out, like the leaves of a book, without doing any real damage, and then the structure of the whole seed can more clearly be seen (Fig. 291).

Between the two flat, kidney-shaped structures, the embryonic bean plant may clearly be seen. It is very easy to distinguish

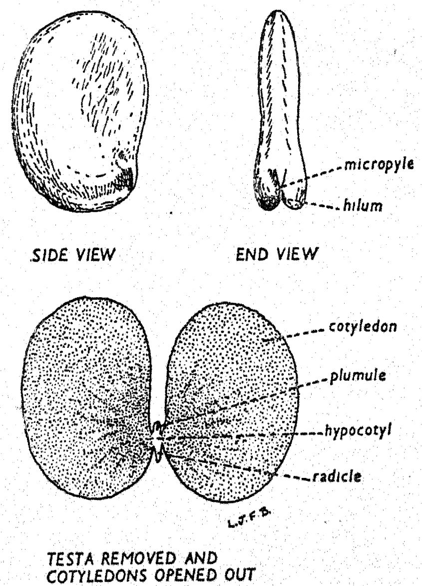


FIG. 291. SEED OF THE BROAD BEAN.

the small cylindrical root, which is called the **radicle.** Opposite to the radicle is the young shoot, known as the **plumule.** The region where the two organs meet is known as the **hypocotyl.** The two large structures, which form the bulk of the bean seed, are each joined to the embryo at the hypocotyl. These two structures are really modified leaves, and are called the **cotyledons.**

In many seeds there are two such cotyledons, and plants which bear seeds of this nature are therefore called **dicotyledons.** On the other hand, a large number of plants such as the

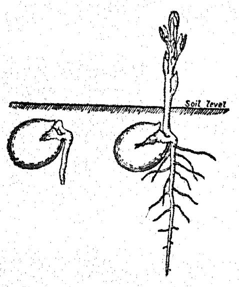


FIG. 292. HYPOGEAL GERMINATION OF THE BROAD BEAN SEED.
(*After Thompson.*)

hyacinth, tulip, lily, wheat and grasses, bear seeds which have only one cotyledon. They are therefore called **monocotyledons**.

The cotyledons, whether they are one or two in number, are really part of the embryo. Now, in the bean, it is clear that apart from the radicle, plumule, hypocotyl, and the two cotyledons, there is nothing else enclosed by the testa. That is, there is only a seed but no endosperm, and therefore the seed is non-endospermous.

However, the bean seed has an adequate food reserve for the young germinating seed. This food is stored in the two cotyledons. That is why the latter are both so very much enlarged. The

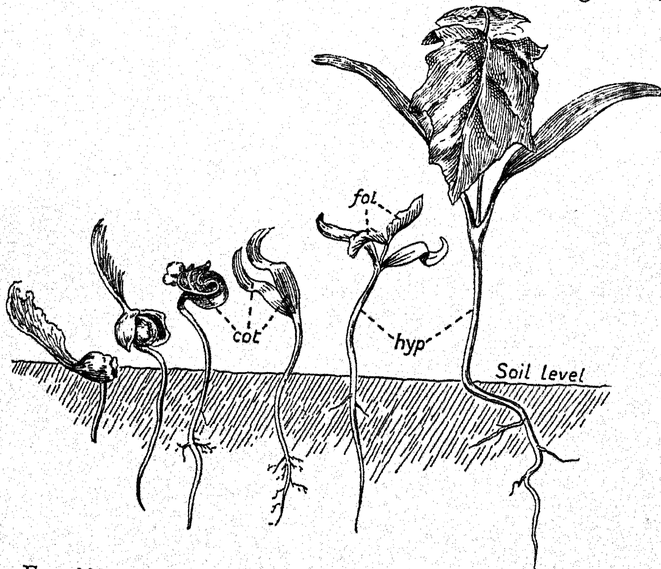


FIG. 293. EPIGEAL GERMINATION OF THE SYCAMORE SEED. *cot.*, cotyledons ; *fol.*, first pair of foliage leaves ; *hyp.*, hypocotyl.
(*Modified from Miller : Cornell University Nature Study Leaflets.*)

stored food takes the form chiefly of starch, together with a certain amount of protein, as can be proved by chemical tests. It is clear from this description, that as the seed germinates and uses up its reserve food, the two cotyledons disappear. Therefore, they always remain with the seed, below the soil. Such cotyledons are referred to as **hypogeal** (Fig. 292).

There are, on the other hand, many dicotyledonous plants in which the cotyledons behave quite differently from this. A good example of this is the sycamore (Fig. 293) and the castor-oil plant (*Ricinus communis*). The sycamore is exalbuminous, whereas the castor oil is albuminous. In the latter, the ovoid seed contains a young embryo very similar to that of the broad bean seed. But the cotyledons are quite different. Whereas in the bean they are thick and fleshy, owing to the food reserve they contain, in the castor-oil seed they are extremely thin, since they contain no food reserve. But then the castor-oil seed is endospermous, or albuminous, and stores its food reserve (chiefly protein and an oil—castor oil) in the endosperm, which is a tissue, enclosed in the seed, but outside the embryo itself.

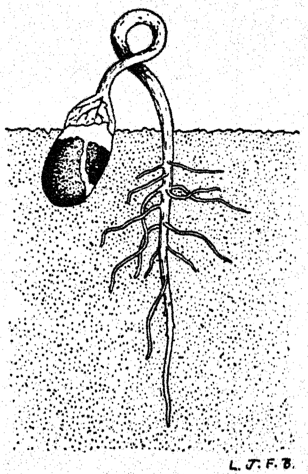


FIG. 294. GERMINATING SEED OF THE CASTOR-OIL PLANT.
The hypocotyl is slowly twisting, thus pulling the rest of the seed out of the soil.

When the castor-oil seed germinates, therefore, it draws on its endosperm for the food supply which it requires during so much activity. The cotyledons are therefore not required for the purpose of storing food. When the young shoot appears above the soil the cotyledons are pushed up with it. After being in the light for some time, they develop chlorophyll, grow to a much larger size, and then act as true foliage leaves. The cotyledons of sycamore, too, are carried above the soil and act as the first foliage leaves (Fig. 293). Seeds which push their cotyledons

above the soil, and thus convert them into foliage leaves, are referred to as epigeal.

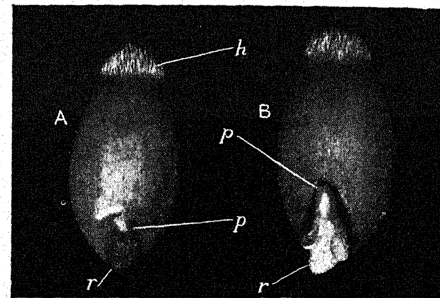


FIG. 295. WHEAT GRAINS.

The embryo with plumule (*p*) and radicle (*r*) is seen through the coat of the grain. *h*, hairs on the top of the grain. In *B* germination has begun.

Another interesting point in the germination of the castor-oil seed is the behaviour of the hypocotyl. In this case, the hypo-

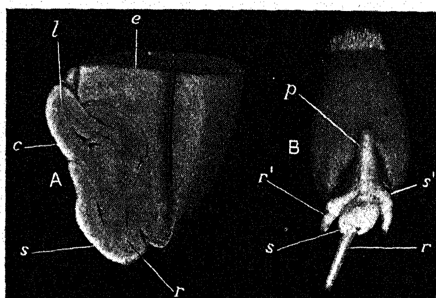


FIG. 296. *A*, LONGITUDINAL SECTION THROUGH THE LOWER PART OF A WHEAT GRAIN.

r, radicle ; *s*, plumule ; *c*, first foliage leaf ; *l*, enclosed bud ; *e*, endosperm.

B, THE PLUMULE AND RADICLE HAVE ELONGATED AND TWO ADVENTITIOUS ROOTS HAVE FORMED.

cotyl is pushed above the soil ; then, during growth it goes through a series of twists whereby it pulls the rest of the seed out of the soil (Fig. 294).

Stages of germination are also well seen in the wheat grain (Figs. 295 to 299), in the photographs of models in the British Museum (Natural History), here reproduced by kind permission of the Trustees of the British Museum.

Conditions suitable for Germination

There are several important conditions necessary for the germination of seeds, but these vary with different seeds. One

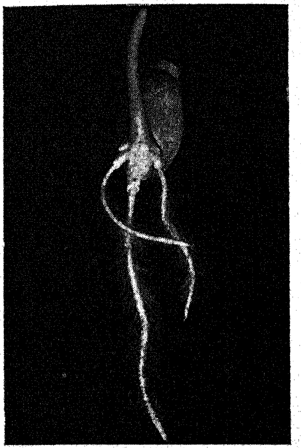


FIG. 297. GERMINATING WHEAT GRAIN.

Germination has proceeded further than that illustrated in Fig. 296, and root hairs have formed.

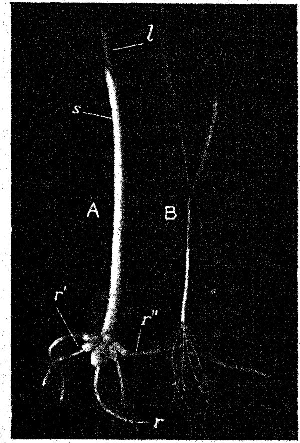


FIG. 298. GERMINATING WHEAT GRAIN.

A, shows the first green leaf ; *l*, breaking through the plumule sheath, *s* ; all roots but one have been cut off short. *B*, a later stage.

thing is essential in all cases ; that is, a supply of water. This is well seen in the case of the pea seed. If some of these seeds be obtained after they have been stored for some time, for example, box peas from a grocer, they will be seen to be very hard and apparently withered. If, then, these peas are soaked for, say, twenty-four hours, they will swell. Then take the peas out of the water, and leave them in a pile, surrounded by a damp atmosphere. After three or four days they will germinate, as shown

by the growth of the radicle out of the seed. This is the first stage in germination of the seed, either in the soil or out of it.

Having absorbed a plentiful supply of water, the young embryo begins to grow by the formation of new cells in its radicle and plumule. Thus the radicle pushes its way out as it grows, through the micropyle into the soil, and continues to grow downwards, finally forming the root. The plumule grows upwards into the air and forms the young shoot. The tip of the radicle usually protrudes first, and, as the young root gets bigger, it makes a large breach in the testa, through which the young, quickly growing plumule can afterwards find its way.

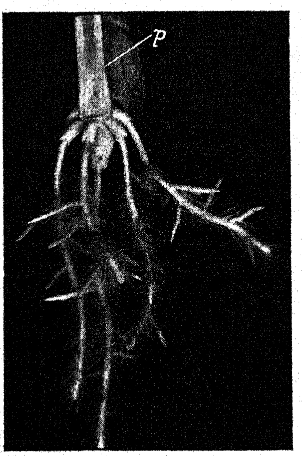


FIG. 299. GERMINATING WHEAT GRAIN.

Lower part of a stage later than Fig. 298, *A*, showing plumule (*p*) in section, and a bud enveloped by the first two green leaves. Lateral roots have formed on the original adventitious roots, which have been cut off short.

All this fast development means the expenditure of much energy. Therefore the process of respiration is taking place at a very high rate. That is why the water is first of all required, for in resting seeds little respiration is taking place, therefore very little water is required.

As has already been seen, respiration takes place at the expense of foods, from which the requisite energy is obtained. In the germinating seed, the foods are supplied by the stores in the endosperm or cotyledons. There are, however, many seeds which have scarcely any food reserve in their cotyledons, and no endosperm at all. They therefore have little food upon which to draw for their respiration. In such cases, the seed must never be sown very far below the surface of the soil, for it must develop quickly at the expense of the little food it has present in the embryo itself, and expand some

foliage leaves from its young shoot above the soil. Then these foliage leaves can make food by photosynthesis.

In the case of endospermous seeds, or seeds which have a plentiful food reserve in their cotyledons, like the bean, there is no such hurry. Therefore the seeds may be sown further down in the soil. It must be realised, however, that so long as the young plant produced by germination remains under the soil, it cannot carry on photosynthesis, owing to absence of light. But, up to a point, in the case of the seeds with a good supply of food reserve, this does not matter, for, so long as the young developing plant can draw on a food supply from its attached seed, it is independent of photosynthesis. Yet its independence cannot last indefinitely, because the food reserve in the seed is bound to come to an end after a time. However, before that time has been reached, the young plumule has pushed its way above the soil, developed its foliage leaves and thus begun photosynthesis. In this way the young shoot takes the place of the fast-disappearing food reserve of the seed, and supplies the necessary food. Naturally, therefore, as the food reserve in the seed is being used up, the seed itself begins to rot away. Finally, the plant has established its roots from the radicle in the soil, its shoot from the plumule in the atmosphere, and thus becomes an independent plant.

Another condition necessary for germination is the presence of **oxygen.** This, of course, is supplied by the air in the soil. The reason for the necessity of oxygen should not be hard to seek. Owing to the great activity in the germinating seed, respiration is heavy. Therefore there is a great demand for oxygen, since oxygen takes a very important part in this process. For this reason, the majority of seeds should be sown in a light soil where there is plenty of air.

Temperature is a very important condition with regard to seed germination as it is in many other plant processes. Above or below a certain range of temperature, germination cannot take place. The range of temperature is that suitable to the well-being of plants in general, and is familiar to the majority of gardeners. The best temperature is that which we get on a summer or warm spring day. With a cold, winter temperature,

on the other hand, seeds cannot germinate, and that is one of the reasons why the majority of seeds are not sown until the spring comes. This effect of temperature is true in the case of *germinating* seeds only—that is, seeds full of absorbed water. Resting seeds can withstand great extremes of temperature. Seeds have been kept at a temperature so low as that of liquid hydrogen (about $-240°$ C.), and also so high as that of boiling water ($+100°$ C.), yet, after being brought back to a normal temperature, have germinated.

The effect of **light** on germination is very complicated, and cannot be properly explained even now. For example, the seeds of the purple loosestrife (*Lythrum Salicaria*), a tall herb which grows on the banks of rivers and ponds, will not germinate unless they are exposed to the light for some time, even after they have become swollen through the preliminary absorption of water. Such seeds are said to be **light-sensitive.** In Nature, of course, these seeds fall on the surface of the soil, and therefore get the desired light for some considerable time. By experiment, however, it has been shown that only a short exposure to light (actually $\frac{1}{10}$ sec.) is all that is required.

Then there are the opposite types of seeds which will not germinate unless they are in the dark. Such seeds are said to be **light-hard.** Examples of light-hard seeds are those of the tomato and of the familiar cultivated plant commonly called love-lies-bleeding or prince's feathers (*Amaranthus*).

Although there are these strange cases of seeds which will not germinate in the dark and those which will not germinate in the light, the majority of seeds do not seem to be affected to any great extent by the presence or absence of light.

Dormancy of Seeds

Seeds differ very much in the time taken for them actually to begin germinating after they have been sown. Germination is usually marked by the time when the radicle first appears through the testa. The length of time which elapses between the date of sowing and the first appearance of the radicle depends upon several factors, one of which is the size of the seed. For example, the seed of mustard, being very small, will germinate in

about a day, whereas a large seed like that of the beetroot will take anything between a week and a fortnight.

Some seeds, as soon as they are shed from their fruit, must immediately find a suitable medium in which to germinate, else they perish. On the other hand, some types of seeds, even after they are fully ripened in the fruit, and shed, will in no circumstances germinate immediately; they wait for some time before doing so, never mind how excellent the conditions for germination. This period which elapses between the ripening of the seed and the time when it is able to germinate is called the **dormant period**, and the seed is said to be **dormant** during that time. In the case of seeds which must be sown as soon as they have ripened in the fruit, there is, of course, no dormant period. In the other cases, the period of dormancy varies with different seeds, from a few days to several weeks.

Viability of Seeds

As is well known in the case of garden seeds, many of them, although they have passed their period of dormancy, are still able to stay in the resting condition for some considerable time, if the conditions are not suitable for germination. Seeds which can 'sleep' for some time before they are awakened into germination are said to be **viable**, and the length of time that seeds can stay 'asleep' is referred to as their **viability**.

This viability of the seed has been the subject of many exaggerated claims; nevertheless, it is true that the viable period of some seeds is quite a long one. In ordinary garden seeds, for example, it is usually at least one year. They are gathered in one season, and then kept in packets until the next. Thus, the ripe seeds have been viable for that length of time. But the gardener well knows that as time goes on, the viability gets less and less, for if such seeds are kept for two years the germination capacity is very much reduced, and a less number of them germinate when sown.

That seeds are viable is also shown in newly ploughed land. The soil in such land is turned, thus bringing to the surface deep underlying layers. Shortly after ploughing, many weeds appear, especially the weed so hated by the farmers, which is called

charlock (*Brassica sinapis*), a plant with bright yellow flowers. The reason why so many weeds suddenly appear on freshly ploughed land is that their seeds have been present in the very deep layers of the soil, where there has been very little air, etc., so that the seeds could not possibly germinate. After ploughing, these seeds are brought up with these lower soil layers into conditions fit for germination, and thus the weeds appear. One famous example is the poppy which germinated and flowered so brilliantly after the shelling of the Somme battlefield during the War. How long those seeds had lain buried, however, is not known. Therefore, all the time that those seeds have remained in the subsoil, they have remained viable. The charlock seed is very viable. It has been known to last for twenty-five years and retain its ability to germinate all that time.

The seeds of the oak, commonly called acorns, will remain viable for one year only, whereas those of the sensitive plant (*Mimosa pudica*) retain their viability for sixty years.

Towards the end of last century it was shown that some kidney-bean seeds which had been kept in the herbarium at Tournefort for more than a hundred years were still capable of germination, and therefore their viability was at least a hundred years.

It has been pointed out that if certain desert wildernesses be irrigated, young date palms almost immediately begin to grow, even though no adult palms are growing nearby. It has been suggested, therefore, that date seeds can remain undeveloped, yet viable, in the soil for many years.

The most interesting seed from the point of view of viability is that of the wheat, since it has been the subject of many curious claims.

Before considering its viability, it is interesting to note how often the wheat fruit is confused with its seed. The familiar grain of wheat, that is, the grain which is used for sowing, is often called the seed. It looks a typical seed, of course, but actually it is the *fruit* of wheat. This confusion arises from the fact that the fruit is of a very curious type. The ovary is formed from one carpel containing one ovule fixed at its base. After fertilisation,

the fruit undergoes very little change, and is therefore very similar to the buttercup achene. There is one important difference, however, in that, whereas in the buttercup fruit the pericarp and seed remain separate, in the wheat fruit the pericarp fuses with the testa of the seed to form one layer. Thus the embryo and endosperm are surrounded by one layer only, which is formed by the fusion of the seed testa and the fruit wall. In such a case where pericarp and testa have fused, the fruit is called a **caryopsis**, and it is easy to see how difficult it would be to separate the seed from the fruit (Fig. 300).

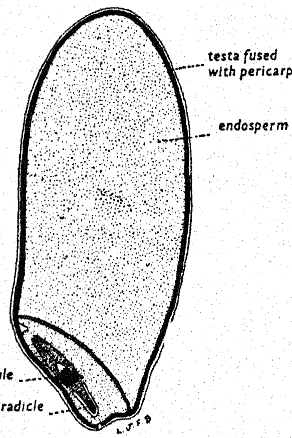


FIG. 300. SECTION THROUGH FRUIT (CARYOPSIS) OF WHEAT.

In 1923 the tomb of Tutankhamen, one of the Pharaohs of Ancient Egypt, who died about the year 1350 B.C., was discovered by Mr. Howard Carter and Lord Carnarvon, who began to excavate it. In this tomb several caskets of wheat grain were found. This wheat was sent to Great Britain and tested to see if it was still viable. It was, as one would expect, found to be dead. Yet, in spite of this, the Press, both in Great Britain and in other countries, announced that this so-called 'mummy wheat' was still viable, and that wheat plants had been grown from it. That is, it was reported in the Press that this mummy wheat had remained alive and viable for close on 3300 years. Wheat from another tomb, estimated as dating back to 1200 B.C., was also sent to the Royal Botanic Gardens, Kew, and there it was tested by the great botanist, **Sir William Thiselton-Dyer**, who found it to be as dead as the mummies themselves.

In spite of all this, belief in the viability of mummy wheat persists in the minds of the public. When, however, the evidence is examined, the result is usually that the person who claimed to

grow wheat from the grain (and probably he really did grow it) had been hoaxed, for it was not mummy wheat at all. For hundreds of years, the present-day native Egyptians have used the tombs as store-houses for their wheat. Probably, therefore, the so-called mummy wheat was some of this. In other cases, it is quite certain that people have been tricked. The idea of the viability of mummy wheat is so widespread that many tourists who visit Egyptian tombs ask the native guides for some of it. Since the guides receive payment for it, they usually manage to satisfy the visitors by getting some ordinary wheat grain and putting it in the tombs when there are no tourists about.

It is quite safe to say, that in spite of certain unsubstantiated claims, the majority of seeds are viable only for a few years, and some for so long as 60 to 100 years, but there is no such thing as seeds of any kind being viable for thousands of years.

Germinating Capacity of Seeds

The farmer and gardener very often want to know the germinating capacity of his seeds. If the number which germinate is a low percentage of the whole, then the seed is considered to be poor. A rough method of testing small seeds is to place some of them in water. Those seeds which sink are capable of germinating, whereas those which float are dead. For commercial seedsmen, however, such a method would be practically useless, for they wish to know much more exactly the percentage germination of their seeds. The way seedsmen test germinating capacity is to plant sets of seeds on trays containing moist cloth, paper, porous earthenware or plaster of Paris, and keep them damp and at a constant temperature. Then the number of seeds which germinate is counted; the number sown is known, and thus the percentage can be calculated. A good percentage of germination is 70 to 85.

Acceleration of Germination

Knowing the conditions necessary for germination, the best methods of hurrying-up the process is chiefly a matter of common sense. The first process in germination is the absorption of water. Therefore, if seeds are soaked in water for twenty-four

hours before sowing, the time taken for their germination will be very much reduced. In the case of large seeds, such as the bean, germination can be hastened by gently piercing the seed-coat or testa in several places with a needle, thus making pores for the water to pass into the seed. Care should be taken not to pierce the young embryo. With hard-coated seeds, such as the coco-nut or castor-oil seed, a part of the testa may be completely removed.

The Seedling

Once the seed has germinated, its radicle soon grows down into the soil and there establishes itself as a root. In some cases, the radicle always remains the largest root and gives off branch roots of secondary importance and smaller in size. This gives a tap root system, for example, carrot. On the other hand, the radicle may grow only to a certain size and other roots may be formed adventitiously from the base of the shoot, equal in size, thus giving a fibrous root system, for example, wheat.

As the root is being developed from the radicle, the plumule is growing up into the air to produce the shoot. In epigeal seeds, the cotyledons are pushed up on the plumule, open out and expand in the air, develop chlorophyll and thus form the first foliage leaves of the young shoot. In the case of hypogeal seeds, the cotyledons remain below the soil and rot away, and the first foliage leaves are developed afresh from the young plumule.

Soon, therefore, the root becomes established in the soil and begins absorbing water and mineral salts from it; the young shoot opens out its foliage leaves which soon begin photosynthesis, and thus the new young plant is established, no longer depending on the seed for food. This young stage of the new plant is called the **seedling**. Once the seedling is established, the seed itself, no longer required, rots completely away. Now established, the seedling carries on growth in the normal way, as will be seen in the next chapter, and develops into an adult plant.

Seedlings, like young babies, are naturally very delicate and need great care. It was calculated, by Charles Darwin, that if *all* the offspring of the henbane (*Hyoscyamus niger*), a plant

which grows on waste patches in Great Britain, though not very common, were to mature to new plants, the whole world would be choked out by henbane plants in three years. If this is the case, then some of the more common plants would choke the whole world in three weeks (see Chap. XXIV). This shows what a tremendous percentage of the offspring of plants never reach maturity. This mortality of the young takes place amongst seeds which never reach suitable soils, and also amongst young seedlings which are either too delicate to withstand extremes, especially of temperature, which adult plants can, or are choked out of existence by more sturdy plants growing around them. As will be seen in Chap. XXIV, there is a constant war being waged between plants for establishment on the soil; and the weaker seedlings lose the fight and die.

Care of Seedlings

In the garden, young seedlings scarcely ever have to overcome the difficulty of fighting against older and better-established plants nearby, for the garden is usually spaced to prevent this; yet the gardener knows that there are other conditions which the seedling has to meet, which an older plant can withstand.

One of the worst is hungry animals. For example, birds are far too fond of picking garden seeds out of the soil, and also of eating the young, tender shoots of seedlings. If a bird were to eat two leaves of an adult plant, it would make scarcely any difference, for the plant would still have plenty of other leaves to carry on its photosynthesis. But, if a bird were to pluck off two leaves from a young seedling, it would probably mean that the seedling would perish because very likely those two leaves were the only ones so far developed. The trouble is that birds prefer shoots of seedlings to those of older plants, since the former are more tender and juicy.

All kinds of methods are used by the gardener and farmer to fight the ravaging effects of birds. Until quite recently, one method used by farmers to keep crows, etc., away from the newly sown wheat fields, was a very simple one. Boys were employed to walk through the fields, whistling and shouting and sometimes using 'clackers.' Another method is to place scare-

crows in the fields and gardens. Seeds such as peas are sometimes protected from slugs and worms by soaking them in paraffin before sowing.

Branches and sometimes cotton are used for preventing birds from getting at garden seedlings. In the case of peas and beans, which are usually planted in shallow trenches, the seedlings are protected by arches of wire netting. The same type of seedlings are protected from slugs, snails and worms, which could otherwise crawl through the meshes of the wire, by a fine layer of sawdust or soot, placed on the surface of the soil around the seedlings. These animals cannot crawl over such a layer.

Many seeds are sown in early spring. Therefore, when the seedlings appear above the soil, they risk attacks from frost, which they cannot resist so well as adult plants can. This is prevented by covering them lightly with a layer of straw.

Sometimes to avoid the risks of attacks from animals and frost, also in order to hasten the early stages of the plant, seeds are sown in germinating boxes and kept in a greenhouse until the seedlings have attained a reasonable size. Then the seedlings are transplanted out into the open soil. This is very frequently done in the case of broad and runner beans, lettuce, onions, and various types of cabbage plants.

A very curious type of seedling is that of the rice plant. The seedling demands an excessive amount of water. Therefore, after the seedlings have appeared above the soil, the rice fields are flooded with water by a process of irrigation, until the water remains on the surface of the soil. After a time, the water is drained off, and the plants allowed to grow to maturity.

PRACTICAL WORK

1. Show that seeds absorb water, to a considerable extent, through their micropyles.

Choose some dry bean seeds and cover their micropyles with a little rubber solution. Allow this to dry and then place the seeds in water. Put some more bean seeds which have not been treated thus, in another vessel of water. Leave both for the same length of time (about twenty-four hours), then see to what extent the seeds have swollen by the absorption of water.

Describe these results and deduce the rôle of the micropyle in the process of germination.

2. Place a piece of blotting paper or cotton wool in a saucer. Then moisten it with a *known* quantity of water. On this blotting paper, sow a hundred wheat grains. Do the same, using a similar sized piece of blotting paper and the same amount of water, with other seeds, preferably garden seeds; for example, cress, radish, onion, beet, carrot, etc. Then record each day the number which have germinated and calculate the percentage. More water may be added to keep the blotting paper moist. Note the diversity of time taken to germinate.

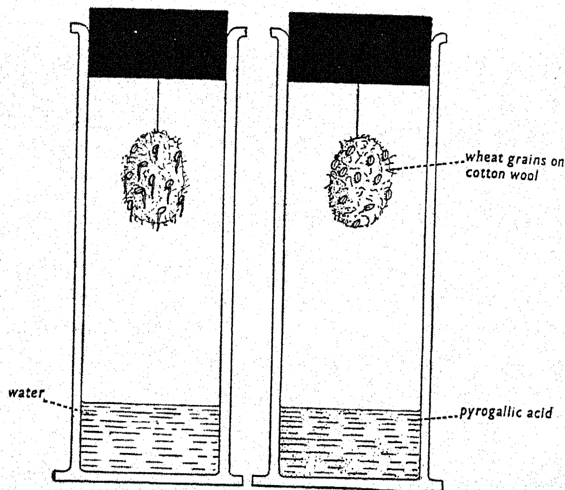


Fig. 301. Experiment for demonstrating the Necessity of Oxygen for Germination.

3. Examine the effect of light on seeds. Set up saucers containing seeds similar to that required for Experiment 2; but having duplicate sets throughout. Place one set in the light and another set in a dark room or box.

Do the same with examples of light-hard and light-sensitive seeds.

Record the results as percentages and from them discuss the effect of light on germination.

4. Test the effect of different temperatures on seeds, by similar methods.

5. Show that oxygen is necessary for germination.

Roll two pieces of cotton wool into spheres, then fix them by means of pieces of cotton suspended from two rubber stoppers (Fig. 301). On each piece of cotton wool, stick fifty wheat grains.

The moisture of the cotton wool is sufficiently strong to hold them. Then fix one stopper in a jar about a quarter filled with water; and the other in a jar about a quarter filled with pyrogallic acid. Make sure that the stoppers are fixed firmly.

Record the number of grains which have germinated each day, and, realising that pyrogallic acid absorbs the oxygen from the atmosphere, deduce the rôle of oxygen in germination.

6. Examine the structure of the seed of the castor-oil plant (*Ricinus*) and the broad bean (*Vicia*). In the latter case it is best to soak it for twenty-four hours before dissecting.

Dissect both seeds and draw the structures seen in both cases. Note in each case the embryo, with its hypocotyl, radicle and plumule. The cotyledons of *Ricinus* are thin and tissue-like, whereas those of *Vicia* are thick and fleshy. Explain why, although in both cases there is an excellent food supply, yet *Ricinus* is albuminous whereas *Vicia* is exalbuminous.

Note the testa surrounding the seed in each case. Test the food reserves present.

7. Plant about ten seeds of the castor-oil plant and ten seeds of the broad bean in boxes containing damp sawdust. Place in a window and allow them to germinate.

Then, after the radicles have appeared, take one of each and make a drawing of it. Do the same at intervals, thus examining the various stages of germination.

Note the hypogeal germination of the bean and the epigeal germination of the castor-oil plant.

Examine and draw the seedlings in detail, and explain why the first foliage leaves of the castor-oil plant differ from its normal foliage leaves, whereas in the bean this is not the case.

CHAPTER XXI

GROWTH

PLANTS are composed of many cells joined together, and growth therefore involves the increase in the number of the cells, by division of one cell into two and so on. It is conceivable that growth could take place in all directions, but actually in real life this is not the case. Growth in every possible direction would result in the production of a sphere, and few plants and animals assume this regular shape. Plants and animals, though they conform to certain types, with regard to their shape, are all irregular. This means, therefore, that in the mass of a plant there are only certain regions where new cells are being produced and new growth taking place.

With reference to ability to grow, plants and animals differ, in general, in two respects. First, plants are more branched and irregular in shape than animals. There are exceptions to this distinction between plants and animals, of course. For example, the green plant, *Spirogyra,* never branches, whereas corals, which are animals, are so much branched that they look very like plants.

Secondly, many plants go on growing indefinitely, year after year. They never cease growing. The elm tree, for example, is continually growing in height, its branches lengthen each year, new branches are formed, and its roots increase in length and number of branches annually. On the other hand, the majority of animals are limited in growth, such as man, and the horse. Here, again, as is always the case in Nature, there are exceptions. For example, *Protococcus,* a plant, is limited in growth, whereas corals are unlimited in growth.

Localised Growth

Growth in plants is very localised. It involves chiefly growth in length of the stem and branch stems, roots and

its branches ; also, in some cases, growth in thickness of stem and root.

Growth in thickness has already been examined. It is produced by the activity of the cambium which forms new wood elements on the inside and new phloem elements on the outside, thus causing secondary thickening. This type of growth, of course, takes place only in certain plants. But growth in length of the root and the shoot is common to all the higher plants.

Now the question is, do all the cells in a stem or in a root divide and produce new cells, thus adding to the length of the organ in question ? In other words, are stems and leaves capable of growing throughout the whole of their length ? The answer is in the negative. No stem or root is capable of growing throughout its entire length.

In studying the structure of the root, it was seen that this organ is covered at its tip with a root cap. Therefore, the region of growth of the root cannot be at the very tip. The region of growth is that region where cell division is going on, that is, the meristematic region. In the case of the root, the region of growth is therefore not at the tip, but a short distance behind it. Actually it is about a millimetre behind the tip and then the growing region stretches down the root for about 3 millimetres, but, in general, no further (see Chap. VIII).

At the tip of the shoot, and also its branches, there is no cap. Here, therefore, the region of growth is actually at the tip. There it is most vigorous, but the growing region stretches some distance down the stem, but with decreasing rate. The whole length of the growing region in the stem is several times that in the root. At the very base of a shoot and at the top of a root, near the hypocotyl, there is no growth in length taking place.

In certain stems there is an exceptional distribution of growing zones. This type is usually found in stems with very pronounced nodes and internodes. In this case, the region of growth is not only at the tip as in normal cases, but also in certain definite zones throughout the length of the stem. Two consecutive zones of growth are separated by a zone which is not growing. This exceptional type of growth distribution is called **intercalary** growth. It is well seen in many grasses. Here,

a zone of intercalary growth is situated at the base of each internode. That is why, if grass stems are examined, the direction of growth of the stem changes slightly above each node.

Rate of Growth

The rates of growth in different plants vary considerably. For example, whereas the growth of the stem of a bean or wallflower shoot is so little in one day as to be imperceptible to the naked eye, certain bamboo stems in Ceylon have been known to grow 16 inches in a day. The reproductive fructification of the stinkhorn fungus, one closely related to the mushroom, offers another example of very quick growth. This fructification springs from the hyphæ beneath the soil, to its full height of six inches in little more than an hour.

The length of the growing region also varies in different plants. In the bamboo, for example, it is many centimetres, whereas in the upright hyphæ of the fungus *Botrytis* it is only 0·02 millimetres.

A comparison of growth rates has been obtained by **Buchner,** whose results are recorded in the accompanying table. From his results it can be seen that some pollen tubes, for example, can increase their length to more than three times the original, in one minute.

Plant organ	*Percentage elongation per minute*
Bamboo shoot	1·27
Bryony shoot	0·58
Bean root	0·45
Grass stamens	60·00
Fungal hyphæ	80 to 120
Pollen tubes	100 to 220

Demonstration and Measurement of Growth

The measurement of growth is no easy matter. To begin with, though we know in a casual kind of way what we mean when we say a plant or animal has grown, yet if we tried to analyse exactly what is meant by such an expression we should

find ourselves up against a very difficult problem. For example, when a thing grows in length, we are quite right in saying that it has grown, but *only* in length ; but, say two things are growing in length and one grows longer than the other, are we justified in saying that the longer one has *actually* grown more than the other ? Answering casually one would say 'yes', and very likely one would be wrong. For example, consider two boys born at the very same minute. Then, imagine the same two boys at the age of sixteen years, one 5 feet in height and the other 5 feet 6 inches in height. It does not follow that the taller boy has grown more than the other. He certainly has grown more in height ; but, whereas the taller boy may be very thin and weedy, the shorter may be broad, muscular, and could give the other boy several pounds in weight. So, here is a difficult problem : are we to judge growth by increase in length, height, thickness, weight, or what ?

It is difficult to say. Growth by increase in weight is the most dependable criterion by which to judge. But the trouble is, in the case of plants, when weighing a plant alive, a great deal of the weight is due to the water present in the plant—its vacuoles, its vessels, etc. The same plant may have a certain weight at one moment, and a few seconds after may have increased it by absorption of water, or decreased it by excess loss of water.

Growth of plants, therefore, is best judged by their dry weights, that is, when all the water has been driven off. The trouble with this method is that it is impossible to compare the growth of the same plant at different times, for, once it has been weighed by the dry-weight method, it is killed, since all its water has been driven off ; and clearly cannot grow any more.

Actually, growth is the resultant of two sets of processes opposing each other. There are processes in the living plant which tend to build up new tissues. The chief of these processes is that of photosynthesis whereby new food materials are added to the body of the plant. Such building-up processes are classed together as **anabolism**, and each process is said to be an anabolic process. Other processes tend to break down

the plant body. The chief of these is respiration in which foods are broken down and used in the production of energy. Breaking-down processes are said to be **katabolic.** Thus, anabolism and katabolism are two directly opposed processes. The resultant of these two is called **metabolism.** If anabolism is greater than katabolism, then metabolism is positive and something is added to the plant. If, on the other hand, katabolism exceeds anabolism, then metabolism is negative and something is taken from the plant. So, if positive metabolism is maintained, then growth takes place ; but, on the other hand, if negative metabolism continues indefinitely, then the plant begins to decay.

The demonstration and measurement of growth, in any definite direction, within the living plant is comparatively easy. The growth in length of the stem, for example, merely involves the measurement of the increase in length of a thing, and this is not very difficult. The only trouble is, growth in length is so slow, normally, that to demonstrate it means magnifying the process many times over. However, this trouble is easily surmounted in more ways than one, as will be seen in the directions for taking such measurements given in the practical work.

Force produced by Growth

During growth, shoots and roots exert a considerable amount of force. For example, the castor-oil plumule, when it gets above the soil, will turn itself into a loop in order to force its seed-leaves, or cotyledons, out of the seed. This is better understood from Fig. 294. The onion seedling will do the same.

In their growth upwards, shoots exert so much force that they can overcome quite considerable opposition. In some cases, it has been shown that shoots exert an upward force, during growth, of 82 lb. per square inch. If a fine net be cast over a young growing plant shoot, it will not prevent the plant's upwards growth, for, provided the net is not too heavy, the shoot will lift the net up with it.

The pressure exerted by roots in their growth is too familiar to need much discussion. They have been known to push rocks apart, and, in the case of trees growing on banks, parts of the

banks have been pushed right away, by the downward growth in length and the outward growth in thickness of the roots.

Grand Period of Growth

No plant organ grows at a constant rate, even if it is kept under constant conditions of food supply, temperature, light, etc. All such organs, when they begin growth, gradually increase their rate of growth to a maximum, then decrease it to a minimum. This sequence of growth rates was first studied by the great nineteenth-century German botanist, **Julius von Sachs.**

Although Sachs did much work in every branch of botany, he contributed more to the study of plant life processes (plant physiology) than anything else. For example, he was the first to discover that in the majority of green leaves, starch is the first *visible* product of photosynthesis. He also did much work on movements in plants. Much of our knowledge of plant growth we owe to him.

The sequence of events in the growth of a plant organ, that is, the gradual increase to a maximum and then the following decrease to a minimum in rate, was called the **grand period of growth** by Sachs. All plant organs have such a grand period. For example, Sachs measured the rate of growth of the first internode of a runner-bean seedling. He obtained his results by measuring the increase in length in millimetres at the end of each day, and found that the grand period lasts about 10 days. During the first day, the internode grew about 1 mm., then it increased its growth-rate until the seventh day, when it grew 14 mm., and from that day its rate declined gradually. The rough measurements are given for each day in the following table and the complete grand period is illustrated in the graph (Fig. 302) constructed from the data obtained by Sachs.

GROWTH IN LENGTH OF RUNNER BEAN INTERNODE

Day	Increase in length	Day	Increase in length
1	1·0 mm.	6	10·7 mm.
2	1·5 mm.	7	14·0 mm.
3	2·4 mm.	8	9·2 mm.
4	6·0 mm.	9	5·5 mm.
5	7·3 mm.	10	2·0 mm.

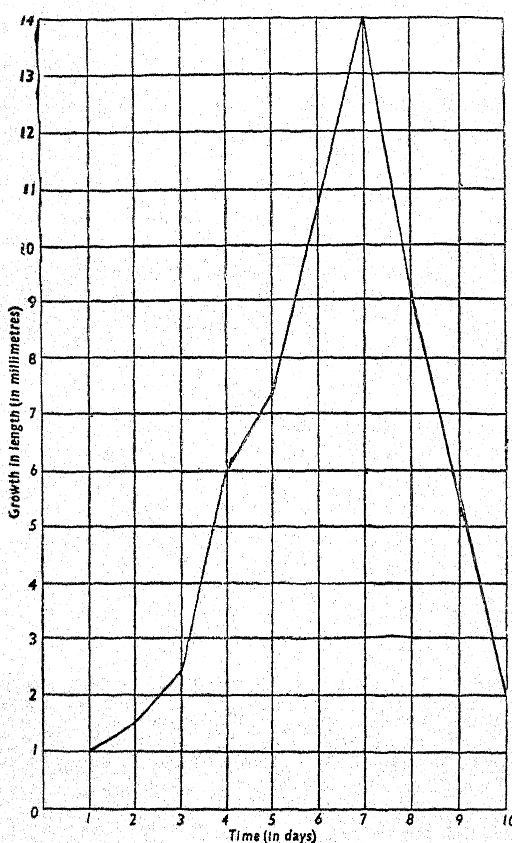


FIG. 302. GRAPHICAL REPRESENTATION OF THE GRAND PERIOD OF GROWTH IN THE INTERNODE OF THE RUNNER BEAN. (*Data from Sachs.*)

Conditions suitable for Growth

The conditions which govern growth are of the utmost importance. These conditions are naturally the same ones which affect anabolic and katabolic processes, and the effect of any one condition on growth is the resultant of the effects of that condition on all anabolic and katabolic processes.

Temperature

An increase in **temperature**, within certain limits, increases the rate of photosynthesis (anabolic) and also increases the rate of respiration (katabolic). But, since *one hour's photosynthesis supplies enough new food for several hours of respiration*, the result is a positive metabolism. The net result is that with increase in temperature, there is an increase in growth. In the case of a radicle of, say, a bean, the growth in length increases in rate, with increase in temperature from 0° C. to about 28° C. Then there is a gradual falling-off in rate, until at about 35° C. growth ceases, since the plant cannot remain healthy at such a high temperature.

Light

The effect of **light** on growth is very complicated, since it affects the various life-processes connected with growth in so many different ways. For example, light is essential to the growth of a green plant, since, without light, photosynthesis cannot take place and of course, without photosynthesis, growth cannot take place. In non-green plants, light is not an important condition for growth.

Growth in length and area, in a green plant, are affected in different ways by light. As will be seen at the end of this chapter, in the absence of light, internodes, leaf petioles, etc., grow much longer, yet their dry weights are much less than similar internodes and petioles grown in the presence of light. On the other hand, growth in the area of leaf blades is very much reduced by the absence of light.

Much work is now being done on the effect of **intermittent light**—that is, periods of light, alternating with periods of darkness. After all, in Nature, plants are subjected to intermittent light (day and night), yet it was not until about fifteen years ago that its importance was realised. Then, a certain tobacco plant (Maryland Mammoth) was found to produce no flowers at certain latitudes, but at other latitudes, where the days were shorter and the nights longer, it blossomed. Since then, much work has been done, and it has been shown that some plants develop

and produce flowers and fruit better by subjection to short-day periods and others by subjection to long-day periods. The chrysanthemum is a 'short-day' plant, and that is one reason why it flourishes during the winter, when days are short. Examples of 'long-day' plants are wheat, barley, oats, love-in-a-mist, clover, etc. Thus, these plants flourish best during that season of the year when days are long. Wheat plants have been subjected to short-day periods by artificial means, and though they developed well vegetatively, they were an exceptionally long time producing flowers and fruit. Length of the intermittent periods of light has other important effects. For example, with long light periods, storage in the onion is accelerated, and the bulbs thus become bigger. In the tropics, where the days are shorter than in temperate regions, certain onions produce no bulb.

Water

Water is a very necessary factor to growth, for without a good supply of water, plants cannot grow at all. This is because all cells must be in the turgid condition in order to divide; and the division of cells is the basis of growth. Thus, we have three very important processes where liquid water is essential in plants: (1) in the process of photosynthesis, since the green cells cannot manufacture food unless they are in the turgid condition (see Chap. XI); (2) liquid water required for translocating mineral salts and dissolved foods all over the plant system; (3) in the process of growth, since cells must be turgid in order to grow and divide.

Nutrition

Nutrition is clearly a very important factor in growth. Undernourishment means reduction in growth, and this applies both to plants and animals. In the case of plants, photosynthesis is one of the most important nourishing media and, so long as this goes on satisfactorily, growth is assured (provided, of course, the other conditions are fulfilled). Naturally, a good supply of the raw materials for photosynthesis is required for good growth. Carbon dioxide and water are usually present in sufficient quan-

tities. But this is not always the case with the mineral salts in the soil. If a farmer or gardener is getting a poor yield from his crops, yet weather conditions, such as sun for photosynthesis and rain for soil water, are reasonably good, then he should see if the soil is sufficiently manured. The following is an example of the effect of soil salts on growth. These results were obtained by experimental work in the field, at Rothamsted Experimental Station. The yield is actually grass which has been dried to form hay :

Complete mineral manure - - -	46 cwt.
Mineral manure, without potash - -	27·3 cwt.

Wounds

Many perennials, especially trees and shrubs, are often subject to the risk of wounding. Sometimes the complete branch of a tree is torn off, thus leaving a large gaping wound. Such a wound may prove a source of trouble to the plant later on. The living tissues, such as cambium and phloem, thus exposed, are easily open to attack by disease-bearing bacteria and Fungi. But the plant prevents such attacks on its exposed living tissue by the activity of the ring of cambium which is also exposed. This layer of active tissue divides rapidly, thus producing a new tissue called callus. The cells of the callus are gradually thickened by cork deposition on their walls. This layer of cork callus is gradually developed until it covers the wound. Thus the wound is protected from the attacks of disease-bearing organisms and also from rain water, which otherwise would get into the wound and cause the tissues to rot (Fig. 303).

Where the wound is of a considerably large area, the cambium is not sufficiently strong to produce a callus to cover the whole area, but it does manage to produce enough to cover the living cells, near the outside edges of the wound. The layers of wood near the centre of the wound are, however, left uncovered. This does not have any great effect, for the wood is actually dead ; but water does get into the wood and cause it to rot away, with the result that a deep pit is formed in the truck, from which the branch was originally torn. The process of rotting is so slow,

however, that it has little effect on the whole plant for many years.

In cultivated trees, such as fruit trees, even the rotting of the wood is prevented, however, by merely covering the exposed surface of the wound with a layer of tar, or lead paint. This prevents water from getting in, and acts just as if the layer of cork callus had actually formed right across the wound including the wood.

In some very old forest trees, the exposed wood caused by wounds has rotted to such an extent, that the trunk of the tree

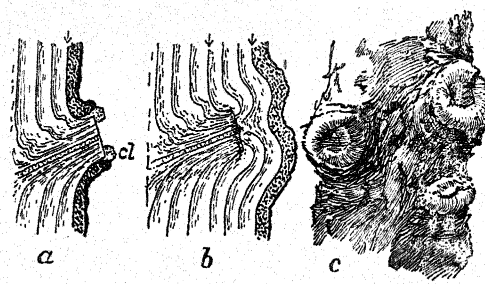


FIG. 303. HEALING OF WOUNDS CAUSED BY CUTTING OFF A BRANCH.

cl, callus which took three seasons of growth to cover the wound as seen in *b*.

(*After Curtis.*)

is completely hollow. This scarcely affects the well-being of the tree, for it has already been seen that the water passes through the sap wood, towards the outside of the woody cylinder, and not through the heart wood. Therefore, so long as there is a certain amount of sap wood left to give the tree mechanical support, and also to allow for the passage of water from the soil up to the leaves, together with the outer phloem tissues to allow the downward passage of food substances, then the tree can live quite safely.

Torn leaves also heal their wounds. When a leaf is torn the layer of exposed cells collapses and dies, thus forming a temporary protective layer over the wound. Then, immediately beneath this temporary layer, a permanent layer of cork is formed,

thus making the leaf tissues completely immune from attacks by disease through the wound. Once the cork layer has become established, the permanent layer of dead cells peels off in scales.

Periodicity

The majority of trees in temperate regions are deciduous and go through a period of rest in the winter. During this season there are no leaves, but there are leaf-buds, commonly called winter buds. These buds remain unopened during the winter and only burst forth with fresh foliage leaves in the early spring. Therefore, such trees experience alternating periods of active life and growth, and quiescent periods of comparative inactivity. This phenomenon is called **periodicity**.

Even if twigs of winter buds such as those of the oak, horse-chestnut or lilac be gathered during the winter and placed in water in a warm room, with plenty of light, their periodicity will not break down. They will not open until the spring ; perhaps a little earlier, but not much. Yet, there are artificial methods of breaking down periodicity, and such methods are sometimes used for getting foliage and flowers ' out of season.'

This can be demonstrated by a simple experiment. Lilac twigs should be gathered during the winter and placed in a vessel of water and the whole thing put under a bell-jar. Then introduce into the atmosphere of the bell-jar a heavy atmosphere of tobacco smoke, and seal the bottom of the bell-jar with some vaseline to prevent the smoke from escaping. Leave this for twenty-four hours, then remove the bell-jar, and place the lilac twigs in a warm, light place. After a few days, the buds will burst and produce foliage leaves. Thus, the periodicity has been broken down by subjecting the winter buds to an atmosphere of smoke. A more efficient atmosphere for breaking down periodicity is that of chloroform. Instead of blowing in tobacco smoke, introduce under the bell-jar a small open dish of chloroform liquid, and leave this for twenty-four hours. Chloroform is a very volatile substance, so within a few minutes the twigs will be in an atmosphere of chloroform vapour. The smoke method is sometimes used by horticulturalists to get a very early crop of flowers such as those of lilac.

Etiolation

Elongation of plant organs, especially stems, is very often retarded by light and hastened by darkness. If a plant, such as that of the broad bean or cress, after it has developed a certain amount of shoot, be placed in the dark for several days, it will be seen that the stem has elongated very much more than it would have in the light. The stem is said to be **etiolated** (Fig. 304). Etiolation of this sort does not necessarily mean an increase in growth, for, as has already been seen, light is really necessary for growth. In the case of the etiolated bean, for example, the stem has grown much longer, it is true, but the leaves themselves are scarcely developed at all. The dry weight of an etiolated plant is much less than that of a similar plant grown normally in the light.

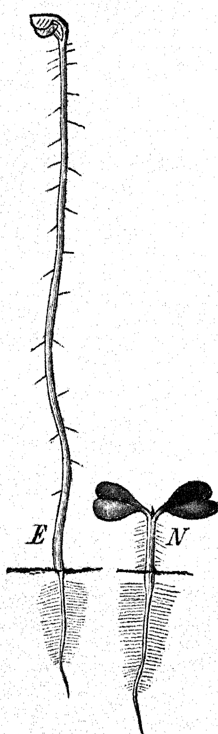


FIG. 304. TWO SEEDLINGS OF WHITE MUSTARD.

E, has been grown in the dark and is thus etiolated. *N*, has been grown in normal daylight.

(*After Noll.*)

This phenomenon of etiolation is familiar to gardeners who keep their own 'seed' potatoes. Of course, these are not really seeds but tubers. When a gardener wishes to keep some 'seed' for next year's planting, he collects them and spreads them out in a cool, dark place during the winter. If these 'seed' potatoes are not used when the time comes, that is, the following early spring, the young buds in the 'eyes' of the potato will shoot out. If, when these shoots are about to develop, the tubers are brought out into the light, the shoots will be short but sturdy, with small deep green leaves. On the other hand, if the tubers are still kept in the dark, the shoots will be etiolated, that is much longer, but sickly-looking, thin,

almost colourless, and the leaves will be nothing more than colourless scales, scarcely developed at all.

In two familiar cases, however, the property of etiolation of shoots in the dark is made use of by the gardener, because it is the etiolated structures that he requires. These two cases are rhubarb and celery (*Apium graveolens*). For cooking purposes, that part of the rhubarb used is the petiole of the leaf. Now a long, pale red petiole is much more desirable than a short, thick, deep reddish-green one. The latter is obtained by covering the growing rhubarb leaves with a tall, chimney-like structure, which keeps the leaves in the dark. This is called 'forcing.' In the dark, the petioles become long, and in this form they are sold in the greengrocers' shops. The lamina of the leaf, however, is very small and almost colourless.

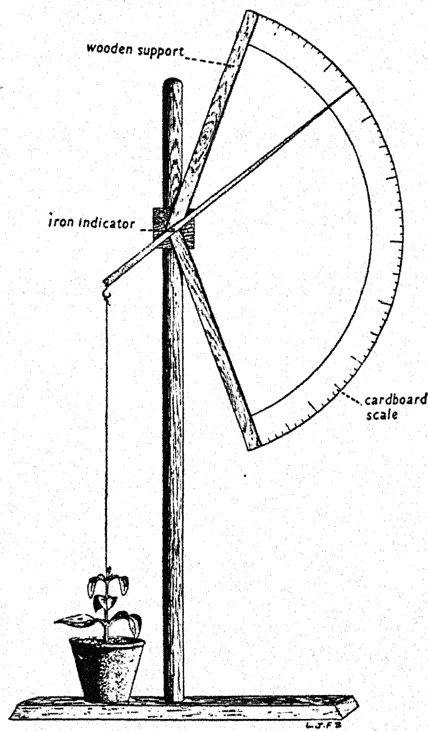


FIG. 305. APPARATUS FOR DEMONSTRATING GROWTH IN A SHOOT.

The celery used as an article of food is also a leaf petiole. The ordinary petiole of a celery leaf is comparatively short, deep green in colour and extremely bitter to the taste; whereas that served up at table is long, white, sweet and crisp. This is because it is etiolated. The etiolation of celery is obtained in a manner quite different from that of the rhubarb. The celery plants are usually grown to the seedling stage in the greenhouse. Then they are transplanted into

deep trenches. After they have partly grown, more soil is put into the trench around the leaf petioles, thus covering them and subjecting them to darkness. Then they become etiolated, and sometimes more soil is added to make them elongate even more. The stringy nature of celery is due to the wood in the vascular bundles which pass up through the petiole.

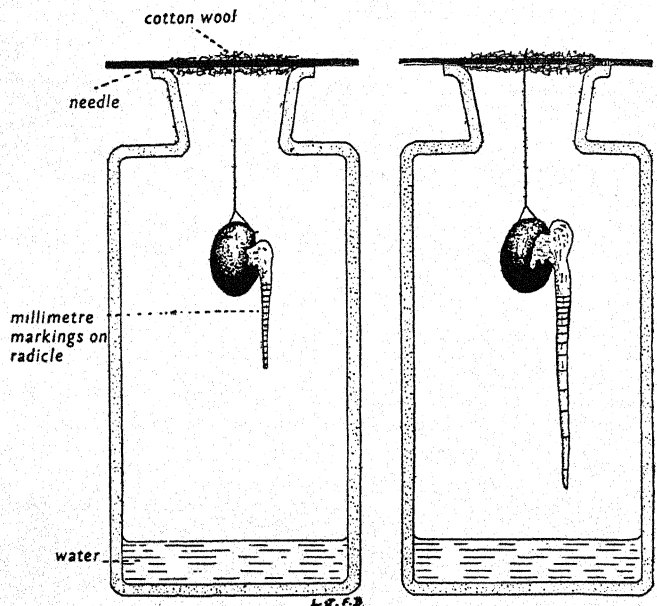


FIG. 306. EXPERIMENT FOR DEMONSTRATING THE REGION OF GROWTH IN A STEM.

Left, at the beginning; right, 2 to 3 days afterwards.

PRACTICAL WORK

1. Demonstrate the growth of a young shoot by means of the apparatus shown in Fig. 305. This apparatus can be purchased, but it is comparatively easy to construct. The materials suggested are shown on the diagram.

2. Germinate a bean seed and when its radicle is about an inch long mark it by means of Indian ink from the tip upwards at intervals of exactly a millimetre, for about 12 millimetres.

Then set it up in the apparatus as shown in Fig. 306 and place it in a dark place. After a few days, examine the original millimetre markings and note how they have moved apart due to the growth of the root.

Describe this experiment and explain why the markings are now separated at irregular intervals.

3. Perform a similar experiment with a young shoot. Sunflower or castor-oil seedlings are excellent material for this. The seedlings may be grown in damp sawdust. Discuss the different result obtained here, compared with that of the root; and explain it.

4. Grow some runner-bean seedlings and, when they are sufficiently developed, take daily measurements of the increase in length of the first internode.

Record these measurements up to about the end of a fortnight and then plot the results in the form of a graph.

Discuss the curve obtained.

5. Germinate two bean seeds at the same time. Then place one in the light and one in the dark. After the seedling produced in the light has attained a height of about two inches, examine and draw both seedlings. Describe from the examination the nature of etiolation.

Obtain the dry weights of both seedlings and explain why although the etiolated seedling is much taller, its dry weight is less than that of the normal seedling.

CHAPTER XXII

MOVEMENT

If a young potted plant, say that of *Fuchsia* or a small broad bean, be placed on its side with the shoot growing out horizontally, after a few days the shoot will be seen to turn upwards (Fig. 307). Similarly, if a bunch of tulips, which are not quite fresh, be placed in a vase, the stalks of the flowers will hang over the side of the vase, with the flowers themselves hanging downwards; but after a few hours the stalks will turn upwards, as they absorb water, with the flowers pointing upwards. In this way, most graceful curves may be produced in the stalk of the tulip. Such curves are clearly due to the activity of the stalks themselves, for the latter cannot be bent straight again without breaking them.

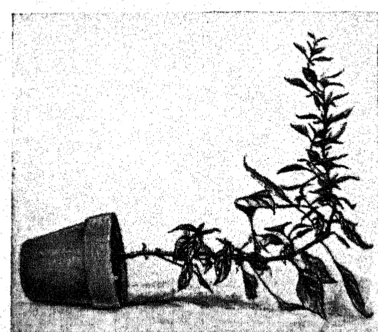


Fig. 307. Experiment for demonstrating Negative Geotropism in a Stem.

In both these cases, there is no doubt that the plant organs have moved. Such movement is very common in plants.

Types of Movement in Living Things

As was seen in Chap. I, an important difference between plants and animals is the fact that the majority of the former cannot move, whereas the majority of the latter can. How are we, therefore, to reconcile the above observations with this

distinction between plants and animals? This is very easy, because there are two distinct forms of movement both in plants and animals.

For example, a person may walk from one part of the room to another. Thus his whole body moves. On the other hand, he may sit in a chair perfectly still except for his moving an arm. In this case, his whole body does not move. Thus we have the two forms of movement, one in which the whole organism moves, and the other in which only an organ of the organism moves, The first type of movement is the one which helps us to distinguish plants from animals, for in plants there are very few cases where the whole thing can move, whereas in animals the majority can. On the other hand, many plants are capable of moving certain of their organs, as already seen in the movement of the shoot of the potted plant and the stalk of the tulip.

That type of the movement where the whole structure is transported is called **taxis**; and that type where only one organ moves is called **tropism.**

Mechanism of Movement

If you put your finger on a hot iron, you very soon take it away again, by quickly moving the arm. There must be some very complicated processes involved in this apparently simple action, for although it is the finger which is affected, it is the whole arm which reacts. The pain is felt in the finger, yet to move it away from the cause of pain, the muscles of the arm have to be called into action.

The best way to understand the processes involved is to trace the details from the placing of the finger on the hot iron to moving it quickly away. The heat of the iron is the cause of the trouble. It is therefore called the **stimulus**, since it stimulates pain. Then next, that pain is felt or perceived by the nerves present just beneath the skin of the finger. This process is called **perception.** Now if one could imagine the finger being severed from the body and placed on the hot iron, it would not move away from it, neither would the arm, from which it had been severed, move. Therefore, in the case where the finger is normally attached to the arm, there must be some kind of connexion which conveys the

stimulus between the finger and the arm muscles. This connexion is supplied by the nervous system, which acts like a telephone system. The stimulus is perceived at the finger tip and this stimulus is then transmitted by some method, not fully understood, to the brain, whence it is retransmitted to the arm muscles. This process of taking the 'message' of the stimulus along the nervous system is called **transmission.** The 'message' is thus transmitted to the arm muscles which then act accordingly. They are said to **respond** to the stimulus.

Thus, in the movement of the arm, four distinct processes are involved: (1) the stimulus of excessive heat from the hot iron; (2) the perception of pain by the nerves of the finger; (3) the transmission of this perceived stimulus along the nervous system; (4) the response of the arm muscle by forcing the arm to remove the finger from the iron.

All four of these processes are involved in tactic and tropic movements both in plants and in animals, though in some cases they are not so clearly defined as in others.

All cases of tactic movements in plants are found in those types of plants or organs of plants which are quite free and are able to swim in water or solution.

In the most important cases, the stimulus which causes the taxis is either light or a chemical substance. The taxis caused by light is called **phototaxis** and that caused by a chemical substance, **chemotaxis.**

Phototaxis

The best case of phototaxis is demonstrated by the freely swimming, unicellular plant *Chlamydomonas* (Fig. 1). If thousands of these plants are placed in a glass of water, the water will appear pale green in colour, since each *Chlamydomonas* plant contains a chloroplast. Now, if the glass be illuminated much more on one side than on the other, for example, by placing it near a bright window, the uniform green colour of the water will soon disappear. This is because all the organisms have accumulated on the more brightly illuminated side of the glass, that is the side nearest the window. This side will be a deep green, owing to the mass of green plants accumulated there.

Now, if the glass be turned through 180°, after a short time the green colour will have changed to the opposite side of the glass, because it is this side that is now illuminated more.

Therefore, *Chlamydomonas* plants are phototactic. The reason for this is clear, for the nearer they are to the source of light, the better can they carry on photosynthesis. The plants perceive the stimulus of light. The region of perception is a little red eye-spot, near the more pointed end of the cell (see Fig. 1). Then this perceived stimulus is transmitted to the cilia, which respond by lashing themselves and thus propelling the plant through the water. The plant, while swimming, not only goes forward, but also rotates on its own axis.

Since the plants swim towards the source of light, they are said to be **positively** phototactic. If, however, the light is very strong (for example, direct, bright sunlight through the window) the plants do the opposite and swim away from the source of light. Then they are said to be **negatively** phototactic. Therefore, *Chlamydomonas* is positively phototactic in subdued or normal light ; but negatively phototactic in very strong light.

Chemotaxis

Chemotaxis is not so easily demonstrated in plants. The stimulus which causes this type of complete plant movement is a chemical substance. For example, certain bacteria are known to move chemotactically towards certain food substances, such as sugar ; but away from certain harmful chemicals, such as acids. They are therefore positively chemotactic to food chemicals, but negatively chemotactic to harmful chemicals. The best type of chemotaxis is demonstrated by the sperms of ferns. In the case of flowering plants, it was seen that the sperms never miss their way to the egg, since they have a definite tube (the pollen tube) through which to travel. With ferns, however, it is quite different. The eggs of the fern plant are borne some distance away from the sperms, and there is no tube connecting the two, as there is in the flowering plant. When both, however, are submerged in water (as is usually the case in Nature), it is possible for the sperm to swim to the egg, for, unlike the sperm of the flowering plant, the sperm cell of the fern has a large number of

cilia. By lashing these cilia, it is therefore capable of swimming in water.

There must be some means, however, of indicating to the swimming sperm the position of the egg, to prevent the former from swimming in the wrong direction. This means of directing the sperm was discovered by a famous botanist named **Pfeffer.** He found that the sperms of ferns are attracted positively by malic acid. He also discovered that the organs of the fern which bear the eggs produce malic acid. Therefore, the malic acid given off near the eggs acts as a stimulus to the sperms, which then swim towards the place of stimulation and thus come into contact with the egg.

A more convincing example of this type of chemotaxis is seen in the case of seaweeds, such as the common sea wrack. In this plant the eggs and sperms are produced and merely cast into the sea. The eggs have no cilia and are therefore quite passive ; but the sperms each have two cilia and are thus able to swim. Yet, since these male and female gametes are cast in a haphazard fashion into the sea, the chances that one of each type will meet to fertilise seem very remote. The chances of failure to meet are reduced, however, by the egg giving off a chemical substance which attracts the sperm. Thus the latter is stimulated chemotactically, and swims towards the egg. What the chemical is in the case of seaweeds is not certain.

Geotropism

Tropic movements and the curvatures that they sometimes cause in plant organs are much more common than tactic movements.

The majority of green plants grow upright. The shoots grow up into the air vertically, and the roots grow down into the soil vertically. If such plants are placed out of the vertical plane, such as in the case of the potted plant mentioned previously, the shoots curve in order to get back into the vertical position again (Figs. 307 and 308).

This property of green plants is due to the action of gravity. Gravity is a force which tends to draw all things towards the centre of the earth. Therefore, roots grow towards the centre of

gravity and shoots away from the centre of gravity. This stimulating effect of gravity which forces a plant to fix itself in a certain position, that is, to orientate itself, is referred to as **geotropism**. It is a tropism and not a tactic stimulus, since it does not make the whole plant-body move, but merely forces certain organs to grow in certain definite directions, and, if they are placed out of such normal positions, it is responsible for making them return to the normal, by curvature.

Gravity, therefore, is the geotropic stimulus. Since the shoot grows away from the centre of stimulation (gravity), it is said to be **negatively** geotropic. The opposite effect in the root can easily be demonstrated. Good material for this is the broad bean radicle, which, of course, is a young root. Plant some bean seeds in sand or sawdust, and when the radicles are about an inch long, carefully remove the complete germinating seeds from the soil. Then, pin them on a piece of cardboard, with the radicles pointing in different directions, one growing downwards, one horizontal, one vertically upwards and one obliquely. Then fix the cardboard upright in a vessel, which contains a little water, and cover the top of the vessel with another piece of cardboard. In this damp atmosphere the radicles will continue to grow, and, after a time, whereas the downwardly growing root will continue to grow downwards, the others will all gradually bend until they, too, are growing downwards. Therefore, roots grow in the opposite direction to stems, that is towards the centre of the stimulation (gravity), so they are said to be **positively** geotropic (Fig. 309).

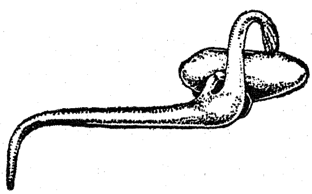


FIG. 308. SEEDLING OF A BEAN PLACED HORIZONTALLY. AFTER A TIME, THE SHOOT CURVES UPWARDS AND THE ROOT DOWNWARDS.

(*After Thompson.*)

When a shoot is fixed horizontally, it gradually turns upwards, because the stimulating effect of gravity is acting on one side of it (the lower) all the time. Now, if the horizontal shoot be continuously turned round and round in the same plane, then gravity stimulates all sides of it, instead of just one. In such a

case, the shoot cannot be expected to turn upwards, since all sides are now stimulated. It therefore remains in the horizontal plane continuously so long as it is kept turning. A method of doing this is given in the practical work. The same applies to a root. Thus, the *effect* of gravity as a geotropic stimulus can be eliminated.

That the geotropic effect is due to gravity can be shown in another interesting manner. A body, such as a stone, if thrown

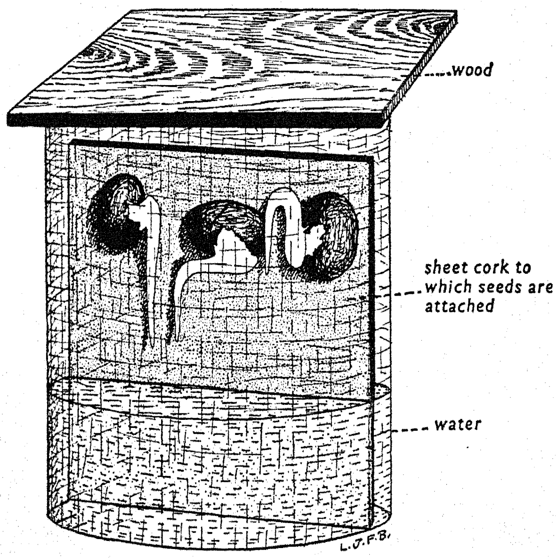


FIG. 309. EXPERIMENT FOR DEMONSTRATING POSITIVE GEOTROPISM IN ROOTS.

into the air, will finally fall to earth by the attraction of gravity. The same applies to small particles of sand. Now, if some particles be placed in a bowl of water, and the water whisked quickly round and round, the particles gradually move towards the centre of the bowl. On the other hand, if some globules of oil be placed on the water, they will move to the edge. Sand is heavier than water, whereas oil is lighter than water. The force which causes this movement in a spinning object is called

centrifugal force. Heavy objects move towards the centre, in such cases, and lighter articles away from the centre.

The effect of centrifugal force on the orientation of roots and shoots was demonstrated in plants by **Knight**, more than a hundred years ago, by means of a turning wheel called **Knight's wheel**. This wheel is very similar in construction to the wheel of a water mill. A wooden one will do, provided with pockets on its circumference, then fitted with an axle. This is placed under a tap of running water, which keeps it turning round continuously. On the circumference of the wheel, germinated bean seeds are pinned, with their roots and shoots pointing in various directions. After a few days, the roots and shoots will be seen to have responded to the stimulus of centrifugal force, the former growing towards the centre of the wheel and the latter in the opposite direction.

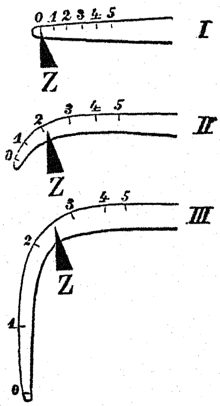


FIG. 310. GEOTROPIC CURVATURE IN A ROOT, SHOWING THAT THE SEAT OF RESPONSE IS COINCIDENT WITH THE REGION OF GROWTH.

I, placed horizontally; *II*, after seven hours; *III*, after twenty-three hours; *Z*, a fixed index.

(*After Sachs.*)

A very important problem in the case of geotropism is to find which parts of the root and shoot perceive the stimulus of gravity and which parts respond. This is quite an easy problem. If some germinating bean seeds be placed with their radicles lying horizontally, they gradually curve downwards, and the point where they curve is that part of the root where growth in length is taking place, namely, just behind the tip. Therefore, the seat of response is coincident with the region of growth (Fig. 310).

Now, if some more germinating seeds be placed in a similar position, but just the very tips of the roots removed before doing so, those roots will not curve, that is, they will not respond to the stimulus of gravity. Therefore, the seat of perception is right at the tip of the root. So, we have perception at the very

tip of the root, but response a short distance behind this. Therefore, there is bound to be some form of transmission from the former to the latter, although the distance is very short. How this is done is still not known. In animals, the stimulus is transmitted along the nervous system; but there is no nervous system of this kind in plants. Therefore, the transmission of stimuli in plants is a problem yet to be solved.

In the case of shoots, response to gravity is very similar. There the seat of perception is at its tip and also the seat of response at the tip, and part the way down the shoot. As we should expect in this case, response, being coincident with the region of growth, follows the latter in being strongest at the tip and then getting less and less going down the shoot. Response very quickly takes place at the tip, but the length of time taken to respond is longer the further it is away from the tip.

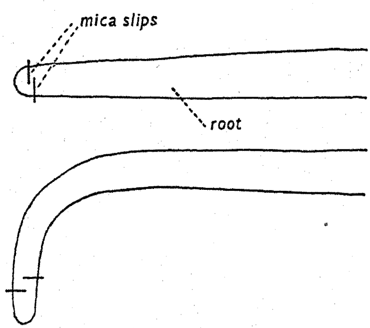


FIG. 311. EXPERIMENT FOR SHOWING THAT TRANSMISSION IN A ROOT IS *not* ALONG ANY DEFINITE CHANNEL.

Above, root placed horizontally after mica slips have been inserted. Below, the same root twenty-four hours afterwards.

Some recent very interesting work has brought out one curious fact about transmission of stimuli in plants. Root tips have been decapitated, then the tips have been stuck on again with gelatine. After they have stuck firmly, they have been stimulated by being placed horizontally and have definitely responded. Therefore, transmission of the stimulus can pass across a non-living layer. Also other experiments, recently carried out at the University of Oxford, has revealed some other interesting features of this phenomenon. Two slips of mica were forced into a root in the positions shown in Fig. 311. Then the root was stimulated by being placed horizontally, and it responded by curving downward in the normal way. Now, if the organ of an animal, such as a man's arm, were treated in this way, there

would be no response to a stimulus applied at the finger, for all the nerves from the fingers to the brain would be severed, at least once. This experiment also shows that transmission of stimuli in plants does not necessarily follow a straight path. It can go round corners. Such experiments as these go to show that transmission of stimuli in plants is probably very different from that in animals.

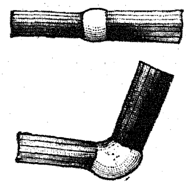


FIG. 312. GEOTROPIC CURVATURE OF A GRASS STEM, BY CURVATURE OF THE NODE. (*After Noll.*)

It has already been seen that geotropic curvature takes place in the region of greatest growth; also that in grasses and certain other plants, intercalary growth takes place at the base of each node, besides normal growth at the shoot tip. Therefore, if a long shoot of grass be placed horizontally, it responds with negatively geotropic curves, not only at the tip of the shoot, but also at the base of each internode, that is, at each node (Fig. 312).

Twining Plants

In the case of twining plants, that is, plants in which the stems are too long and thin to support their own weight, the phenomenon of geotropism in the stem assumes a curious nature.

Stems twine by twisting spirally around a support such as the stouter stem of another plant growing nearby, or stretched cord placed there for the purpose, as in the case of certain cultivated runner beans. In such cases the shoot tip is not merely growing upwards by negative geotropism, but it is also describing definite circles. In doing this, the tip really describes a spiral, for as it moves slowly round and round, it is also moving upwards. Thus, by tracing a circle, it coils round the support, and by negative geotropism it tends to move upwards, which pulls the whole stem tightly round the support. This spiral movement of the tip of the shoot is called **circumnutation.**

Phototropism

If a small plant be placed in a large box which is completely covered except for a narrow slit which allows light to enter at that end of the box furthest from the plant, after a few days, the

shoot will curve in the direction of the slit. This shows that the shoot is sensitive to the stimulus of the directive action of light. If the light is supplied all round a shoot, of course, there is no curvature, since the stimulus is then applied in all directions.

Curvature due to the directive action of light is called **phototropism.** Since the shoot curves towards the light it is said to be **positively** phototropic. Nearly all green shoots are positively phototropic, and response takes place normally in the region of greatest growth. Many plant organs show negative phototropism, that is, they curve away from the direction of light. Some roots do; but one must be a little circumspect in this case, since roots are usually growing in the soil, and therefore seldom experience light at all. Consequently, by far the majority of roots do not respond to the stimulus of light, even if they are exposed to it.

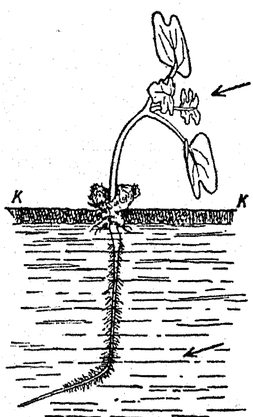


FIG. 313. SEEDLING OF WHITE MUSTARD WHICH HAS BEEN FIRST ILLUMINATED FROM ALL SIDES, THEN FROM ONE SIDE ONLY (INDICATED BY ARROW). (*After Noll.*)

Those roots which do respond, however, are usually **negatively** phototropic. Familiar examples of roots which do not respond to the phototropic stimulus of light are those of the bean and the sunflower. A good example of one which does is that of the mustard.

An excellent method of demonstrating the positive phototropic curvature of the shoot and the negative phototropic curvature of the root can be used with this plant. A small seedling of it is taken and fixed through a hole in a piece of sheet cork, the hypocotyl being supported at the hole by plugging with cotton wool. Then the cork is floated on water in a glass vessel which is covered with brown paper, or painted with Indian ink, except for a slit down one side. Through this slit the light passes, and after a short time the shoot will curve towards it and the root away from it (Fig. 313).

Transverse phototropism is confined almost completely to leaves. In this case, the organ orientates itself at right angles to the direction of the light. In normal light, the leaf blade faces the light, in order to get the maximum for photosynthesis. In very bright light, they turn edgewise to it.

The region of perception of phototropic stimulus is the same as that for the perception of geotropic stimulus, that is, the tip. This can easily be proved in a shoot. If a young shoot be covered with some tinfoil, except the very tip, and then stimulated phototropically by being illuminated on one side only, clearly it cannot respond, because the tinfoil prevents curvature. But it can be proved that the tip has perceived the stimulus by now removing the foil, and then illuminating the shoot all round. Normally, a shoot illuminated all round does not curve, but this shoot will curve in the direction of the light by which its tip was originally illuminated. That it is only the tip which perceives the stimulus can be proved by carrying out the converse experiment. That is, expose the whole of the shoot, except the tip; but cover the latter with foil. Then stimulate phototropically by illuminating on one side only. It will not respond.

Chemotropism

Movement, or curvature of a plant organ towards a chemical substance, is referred to as **chemotropism**. The growth of pollen tubes, for example, is directed towards the ovules by a sugary substance. Thus the tubes exhibit chemotropism, the stimulus being supplied by certain sugars present in the style of the ovary.

Hydrotropism

Hydrotropism is a special case of chemotropism, where the chemical substance is water. In soils, for example, where the water is not evenly distributed, the roots will sometimes curve out of the vertical towards the most efficient water supply. Thus, sometimes in its normal habitat, the direction of growth of a root is determined by water as well as by gravity. This can be demonstrated in a simple experiment which is described in the practical work.

Contact Stimulus or Haptotropism

Contact with an outside body sometimes acts as a tropic stimulus in plants. Tendrils, for example, when they come in contact with a supporting branch, receive a stimulus by such contact, and they respond by a growth curvature whereby they coil round such a support. Tropic curvature of this nature, due to the stimulus of contact, is sometimes referred to as **haptotropism.**

The direction of growth is sometimes influenced by other conditions. For example, plants in exposed conditions are often subjected to a prevailing wind coming chiefly from one direction. Such plants often respond by growing away from the direction of the wind.

Night and Day Movements

There are certain movements in special cases of plants which, though tropic, are not like the tropisms so far concerned, in that they are not due to the stimulus of any directive force. In the case of the tropisms about to be considered now, the stimulus is **diffuse**, that is, it is present all round the plant, and does not come from one direction only. Such movements are not movements of orientation, that is, they are not of such a nature as to compel the moving organ to arrange itself in a definite position with relation to the stimulus. These movements, due to a diffuse stimulus, are called **nastic** movements. There are several forms of them grouped according to the nature of the diffuse stimulus. Whereas they have a certain amount of significance in some cases, according to Goebel, they are practically useless in others.

Certain leaves and floral organs assume different positions during the night from what they do during the day. The capitulum of the daisy, for example, closes up at night, and so does the flower of the lesser celandine. Such movements are often referred to as sleep movements, though it must be realised that such movements are not in the least bit comparable to sleep in animals. Such movements due to night and day are called **nyctinastic** movements.

Now, when night falls, quite a complicated change in surrounding conditions arise, the two chief changes usually being a fall in temperature and, of course, a great reduction in light intensity. Some nyctinastic movements are due to the stimulus of change in temperature (**thermonasty**), whereas others are due to the stimulus of change in light intensity (**photonasty**).

Splendid examples of thermonastic movements are seen in the flowers of the crocus (*Crocus sativus*) and tulip. At nightfall, the perianth segments of these flowers close up, and when day breaks again, they begin to open out. That this nastic movement is due to the stimulus of change in temperature, rather than light intensity, is easily proved in the case of cut tulip flowers. If such flowers are brought indoors, and placed in a warm room, even if the room is badly illuminated, the flowers will open right out. This movement is sometimes surprisingly quick, the flowers opening in less than half-an-hour.

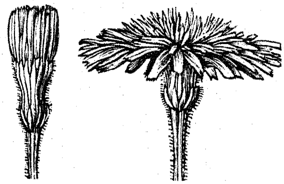


FIG. 314. FLOWER HEAD OF ROUGH HAWKBIT, CLOSED WHEN KEPT IN THE DARK; OPENED WHEN ILLUMINATED. (*After Detmer.*)

Photonasty is even more interesting, since whereas the stimulus of light intensity brings about a certain response in one case, the same stimulus brings about an *opposite* response in another. For example, flowers of the water-lily, many cacti, and the lesser celandine, also the flower heads of the daisy and hawkbit, close up with a great reduction in light intensity, that is, at nightfall (Fig. 314). On the other hand, the flowers of the evening primrose (*Œnothera biennis*), the bladder campion (*Lychnis inflata*), and species of *Nicotiana* (a great favourite with gardeners for herbaceous borders) are quite the reverse in their photonastic movements and open when night falls. That is why certain of these plants, especially *Nicotiana* and the bladderwort, have such a delightful perfume in the twilight and even at midnight, whereas they have none during the day.

The opposite effects of the stimulus of light intensity on photonastic movements can be explained by the type of pollination which such flowers require. Those that open during the day are

pollinated by insects, such as bees, which are only available at that time. Thus, such flowers expose their sexual organs during the day. When night falls, they close up, probably in order to protect such organs from the cold, rain, etc. On the other hand, those flowers which open at night are usually pollinated by night moths.

Certain foliage leaves also exhibit nyctinastic movements, though the reason for this, and what the real stimulus is, is not fully understood even to-day. This is the case in the runner bean (*Phaseolus multiflorus*) leaf and in *Amicia*, a plant native to

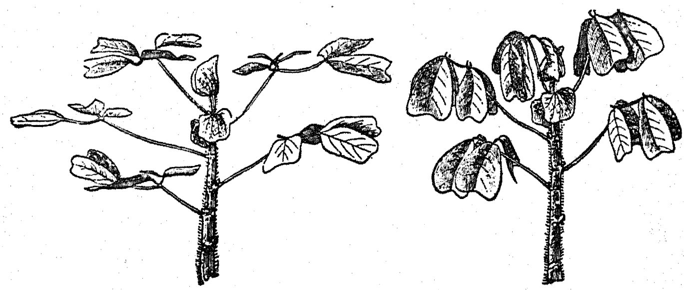


FIG. 315. *Amicia zygomeris*, SHOWING DIURNAL AND NOCTURNAL POSITION OF LEAVES.

the Andes (Fig. 315). In such cases, the leaves are expanded and lie in the horizontal plane during the day, thus being in the best position for photosynthesis. During the night, each leaflet falls vertical, thus giving a kind of closed effect.

Movement due to Wounding

A very interesting, but rare case of nastic movement is seen in the case of the so-called sensitive plant (*Mimosa pudica*), in which the leaves quickly close up, and the whole petiole falls into an oblique position, under some disturbing stimulus, such as wounding. This is therefore called **traumatonasty**. The leaf of this fascinating plant is composed of many leaflets (see Fig. 316). If the whole leaf be struck sharply by the hand, all the leaflets move together, and then the whole leaf falls into an oblique position from its base. This leaf base is very well articulated and

acts like a complicated hinge. It is called the **pulvinus**. The whole reaction to the stimulus is fascinating, since it takes place completely in a matter of a few seconds. The stimulus is not necessarily one of touch, for if a lighted match is brought near the leaf, the same response takes place; also in darkness.

The passage of the transmission of the stimulus is clearly seen by putting a naked flame near the leaflets at the tip of the leaf.

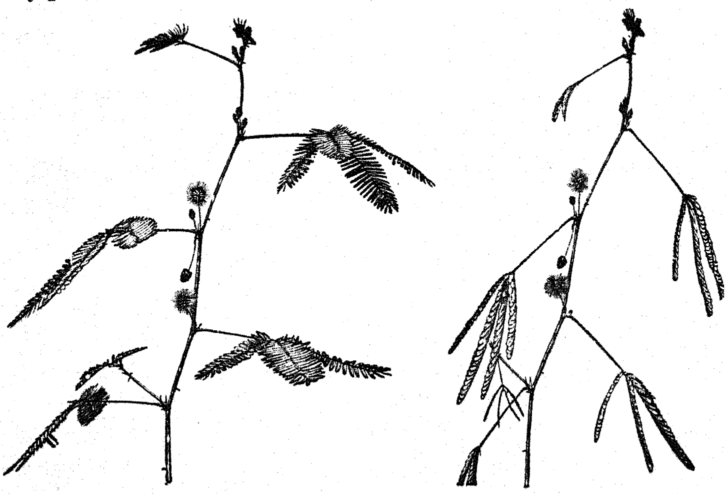


FIG. 316. *Mimosa pudica*, SHOWING LEAVES IN NORMAL POSITION (LEFT) AND AFTER STIMULATION (RIGHT).

The nearest leaflets will close, then the ones next to these, and so on, thus marking the transmission of the stimulus downwards. When it gets to the pulvinus, the whole leaf bends obliquely, then, if the stimulus has been sufficiently strong, it will continue down the stem of the plant to the next leaf. In this second leaf, as one would expect, the stimulus affects the pulvinus first, then it is transmitted up the leaf, that is, in the opposite direction to that in the first leaf. Thus the sequence of events in the second leaf's response are the reverse to what they were in the first. This gives a clear demonstration of the transmission of the stimulus through the leaves and stem of this plant (Fig. 316).

PRACTICAL WORK

1. Examine some living specimens of *Chlamydomonas* mounted in water under the microscope and note their tactic movements. Obtain a plentiful supply of these plants and keep them in a jar of

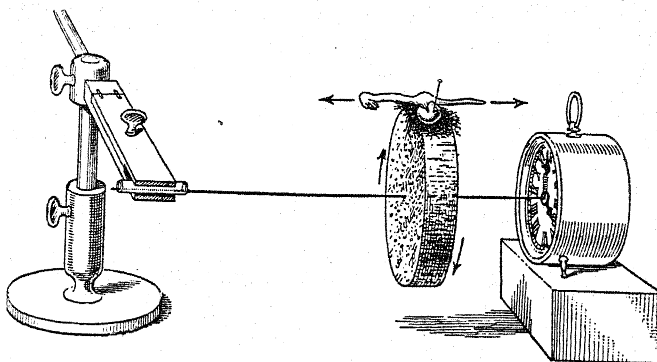


FIG. 317. A KLINOSTAT.

water in a window. Note that after a time the side of the jar nearer the window is perceptibly green, whereas the opposite side is not. Discuss this.

2. Place a potted plant on its side and leave it for some time turned towards the light. After a time, the shoot turns upwards.

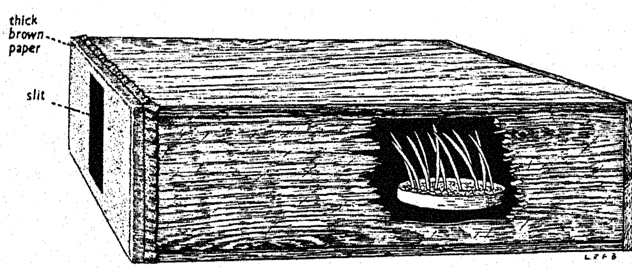


FIG. 318. EXPERIMENT FOR DEMONSTRATING POSITIVE PHOTOTROPISM IN SHOOTS.

Discuss this, and explain why, in order to demonstrate negative *geotropism* thus, it is necessary to turn the plant towards the light.

3. Germinate three bean seeds and, when their radicles are about half an inch long, fix them all by means of pins to a piece of

cardboard or sheet cork, taking care that the pins do not pierce the embryo. When fixing them, arrange one radicle pointing downwards, the second horizontally and the third upwards. Then place the sheet upright in a jar of water and cover with a piece of wood or cardboard (Fig. 309).

Put the apparatus in a dark place and after about two days examine and draw the results. What conclusions are to be obtained from these results ?

4. Perform a similar experiment, but in this case cut off the tip (about $\frac{1}{2}$–1 mm. back) of each radicle.

Compare the results obtained with those of Experiment 3 and discuss, from these combined results, the phenomena of stimulus, perception, transmission and response in plants.

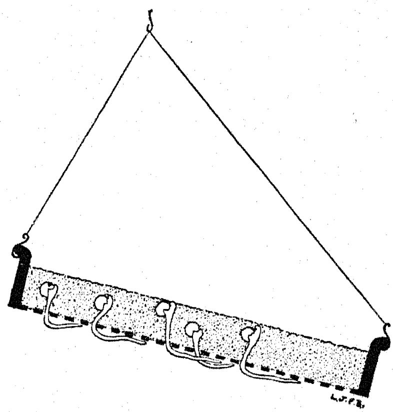


FIG. 319. EXPERIMENT FOR DEMONSTRATING POSITIVE HYDROTROPISM IN ROOTS.

5. Fix up the apparatus as shown in Fig. 317. This apparatus is called a **klinostat.** Since the axis is fixed to the axis of the minute hand of the clock, the seedling is kept moving in a vertical, circular path. Note that as a result the shoot does not turn up, nor the root turn down. Explain this with reference to the stimulus of gravity.

6. Germinate some wheat grains in damp sawdust placed in a saucer. After the shoots are about two inches high, place them in a dark box, lying on its side. Then cover the end of the box with stout brown paper, with the exception of a narrow slit (Fig. 318).

Place the box with the slit turned towards the light, and leave it for about two days. Then examine the seedlings and discuss the phenomenon of positive phototropism from the result obtained.

7. Demonstrate positive phototropism in the shoot and negative phototropism in the root of white mustard.

Fix up the seedlings as shown in Fig. 313, then place the whole on a vessel of water culture, with the root in the water. Then place the whole apparatus in a box illuminated at one end as described in Experiment 6.

After about two days draw and discuss the results obtained.

8. Demonstrate positive hydrotropism in roots.

Fill a small, rather coarsely meshed sieve with damp sawdust Then sow some cress seeds in the sawdust, and when the radicles are beginning to protrude through the meshes, suspend the sieve obliquely (Fig. 319).

After a few days, note the results. Since more water will be found at the lower end of the sieve the roots grow towards it.

Field Work

Examples of nastic movements are best observed either in the garden or the field. As many types as possible should be examined, and drawings made of the examples in various positions.

CHAPTER XXIII

THE PLANT AND ITS SURROUNDINGS

To know the relations which exist between a plant and its surroundings (or **environment**), both below the soil and above it, is a great help in appreciating why the plant grows best in a certain locality and on a certain soil, and it is an absolute necessity in the cultivation of plants; whether extensively as in agriculture, or intensively as in horticulture.

Soil

In the normal land-growing (**terrestrial**) plant—and this includes nearly all the important plants from man's point of view—the soil forms the environment of the roots.

Soil which covers most of the land above sea-level is formed from the rocks on which it is immediately situated. In its original state, the land was composed of nothing but bare rock. Of course, some such rocks are seen exposed even to-day. By various means, which will be examined shortly, the rocks have crumbled or **eroded**, thus producing the soil particles. Naturally, various soils are produced according to the various rocks from which they are formed.

As one would expect, there is no hard and fast line between the top soil and the rocks beneath, from which it has been formed. However, between the real top soil and the rocks there is usually a more or less definite layer composed of stones intermediate in size between the large boulders of the rock and the very much smaller soil particles. This layer is referred to as the **subsoil**. The three layers, (*a*) rock, (*b*) subsoil, (*c*) soil, can be easily distinguished where it is possible to examine the soil in profile, such as on the edge of a quarry or the top of a cliff (Fig. 320).

The soil and the subsoil layers vary considerably in different localities, the thickness of soil being dependent upon the hardness of the rocks and the amount of erosion that has taken place. Usually the thicker the layer of soil, the more fertile it is from the point of view of plant production, wild or cultivated, since it is only in the soil that the roots are able to find the necessary water, air and humus.

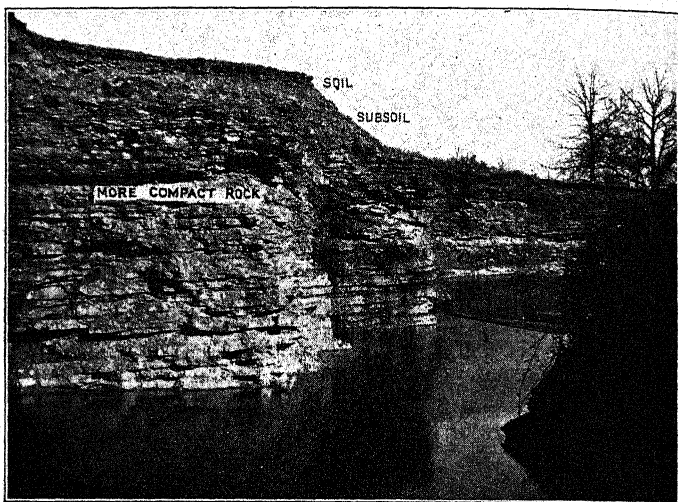


FIG. 320. PHOTOGRAPH OF A QUARRY, SHOWING THE ROCK, SUBSOIL AND SOIL.
(*By courtesy of the Director, Geological Survey.*)

Erosion of rocks, resulting in the formation of soils, is dependent upon several factors. The main factors are those concerned with the weather; and their effect is often referred to as weathering. Rain, sun and frost all play their part. For example, the rain gets into the crannies of the rocks; then along comes the frost. This causes the water to freeze, which, as is well known, results in an increase in volume. This has the effect of pushing the pieces of rock apart. It can be shown in the case of a piece of limestone, which is fairly soft. If limestone is covered with water and then put out into a frosty air and left for

a few days, the surface will be found to be covered with a fine powder which is nothing but very fine limestone particles similar to those in a limestone soil.

Growing plants and animals also help in the making of soil. Charles Darwin showed that earthworms are very effective in bringing up soil particles from the lower layers to the surface, thus very effectively turning the soil as it is turned in digging and ploughing operations. In the lawn of Darwin's home at Downe in Kent, there is a round stone which has sunk some considerable distance in the soil. This stone was originally placed on the surface of the lawn, and Darwin showed that its sinking in the way that it has (it can still be seen there sunk several inches in the soil) was due to the activity of earthworms in the soil. The worms, which get their nourishment by eating soil and then discharging it again after having absorbed any nourishing humus in it, have brought the soil up from beneath the stone and deposited it around the stone. Hence its having sunk some considerable distance into the soil.

Composition of Soil

As has already been seen, the roots of the plant require water, air, and organic matter or humus from the soil. The average garden soil which may be considered a rich one should contain the following ingredients, the numbers representing percentage by volume :

Rock particles	40
Water	25
Air	25
Humus	10

The rock particles constituting the actual soil vary in size according to the rocks from which they have been formed. The three most common rocks which aid in soil formation are sandstones, clays and limestones. The average soil, of course, is composed of a mixture of these, the percentage of each varying with different localities. Then, in many cases, the soil is further characterised by the presence of other substances. For example, the very white, limy (or calcareous) soils of Kent and Sussex are due to the presence of chalk. The red soils of Devonshire and certain parts of Somerset owe their colour to the excess amount

of iron salts in the soil, and the fact that they are formed from red sandstone. Soils very rich in humus are usually dark in colour. Soils containing a great deal of lime are alkaline in reaction, whereas those which contain excess water and humus, such as bogs and marshes, are very acid in reaction. All this is important from the point of view of the plants which will colonise these soils, for certain plants must have very acid soils, whereas others must have limy soils, etc.

The largest particles in the soil are the **stones** and **gravels**. With too many such large particles, the soil would be very poor, since they cannot retain water. **Sand** forms very coarse soil particles. **Clay**, on the other hand, is composed of very fine soil particles. So coarse is sand, that a mass of such particles will not hold together unless saturated with water, and then not very firmly. On the other hand, a mass of clay particles hold together very tenaciously, forming a plastic mass. Intermediate between soils and clays are those particles called **silt**.

A typical soil contains a certain percentage of all these various soil particles, the percentages varying with different localities. A soil which contains chiefly sand and silt, with about 6 per cent. of clay, is called a **sandy soil**. If it contains more than 25 per cent. of clay it is said to be **clayey**. Between the two, we have the more common type of soil, with plenty of sand and of clay. Such a soil is called a **loam**. Sir John Russell gives the following as being a typical loam : clay, 6-15 per cent. ; silt, 40-60 per cent. ; and sand, 20-50 per cent. If an exceptional amount of calcium be present in the soil in the form of calcium carbonate, such as limestone or chalk, the soil is called a **marl**. A marl is usually a rich soil, since the calcium it contains serves a double purpose. First, calcium is one of the raw elements required in the plant's nutrition. Secondly, calcium carbonate is an alkali and thus prevents the soil from becoming acid or sour.

It is comparatively easy to tell whether a soil is acid or alkaline. In the case of marls, the reaction will clearly be alkaline. The presence of the limestone can easily be detected by adding a few drops of concentrated acid, such as hydrochloric, to some of the soil. The reaction with the excess amount of calcareous alkali can easily be seen by the effervescence which takes place. A very

acid soil, which clearly contains no limestone, is very often detected by collecting some soil water and testing with litmus.

Clay is colloidal in nature and therefore has a very high water-retaining capacity. Drainage from clayey soils, therefore, is very difficult. Naturally, holding the water so tenaciously as a clayey soil does, it is very badly aerated and is heavy. Also, since it is saturated with water, it tends to remain cold. Therefore, a very clayey soil is heavy, badly aerated and water-logged. Crops grown on such soils are usually poor and slow to ripen. In agriculture and horticulture such soils are very often improved by adding larger particles such as sand or ashes from coal and coke fires.

Sandy soils are the reverse. They allow an easy percolation of water and therefore remain very dry, sometimes too dry. They are also very well aerated and therefore extremely light. Crops grown on very sandy soils sometimes suffer from the want of water, etc., so a sandy soil is really not much better than a clayey soil, although it is the reverse in composition. Such soils are usually improved by adding heavy farmyard manure, for with such easy water drainage through a sandy soil, the leaching of mineral salts goes on at an excessive rate.

It is quite clear that, on the average, loams are the best soils for crops, etc. A rough mechanical way of showing the constitution of a loam is to stir a little of such soil in a beaker or glass of water. The heaviest sandy particles will soon settle to the bottom of the glass. Closely following the sand will be the silt which will settle above it. The clay particles, on the other hand, being very small and colloidal, will remain suspended in the water, whereas the actual humus will float. The alkalinity or acidity can then be examined by testing the reaction of the water.

The size of soil particles has a great effect on the physical properties of the soil, and this is important, since a great deal, from the plant's point of view, depends upon the physical nature of the soil.

The colour of the soil is an important physical property, for a dark soil absorbs more heat from the sun's rays than a light soil does. Thus, the temperature of a dark soil is higher than that of a light soil under similar conditions. The temperature of the

soil is also affected in two other important ways: (*a*) degree of slope towards or away from the sun, for the more the soil slopes towards the sun, the warmer it becomes; (*b*) amount of evaporation of water from the soil. Evaporation from a surface has a cooling effect on the surface, therefore the more the evaporation takes place, the cooler does the soil become. Naturally, a very loose, sandy soil has a much higher degree of evaporation than a compact clayey soil.

The rate of passage of water through the soil is also of great importance. As was seen in Chap. VIII, the soil water is usually present on the surface of the soil particles. Now, passage through the air channels is due to the process of **capillarity**. It can easily be shown that the smaller the bore in a glass tube, the greater is its capillary attraction. Place several tubes, with very small, but varying bores, standing in water. By capillarity, the water will pass up the tubes, but the height to which it rises varies inversely as the diameter of the bores of the tubes. Therefore, the smaller the diameter, the greater the capillarity. Thus, in soils, passage of water will be greatly affected by the soil particles. The smaller the particle (for example, clay) the smaller the air spaces, and therefore, the greater the capillarity. The result is that water moves upwards by capillary attraction much more quickly in a clayey soil than in a sandy one.

The physical properties (such as size of particles), chemical properties (such as water-content, manure), and biological properties (such as the soil bacteria) of soils are all of the utmost importance to plants. So also are the conditions to which the shoots are subject, such as meteorological (weather) conditions, temperature, light and so forth.

Plant Environment

A wild plant has no choice in the situation in which it shall grow, that is, its habitat. If it is fortunate enough in arriving, as a seed, at a suitable habitat, then it thrives; if, on the other hand, it finds itself in an unsatisfactory habitat, then it either perishes or is badly developed. With cultivated plants things are different, for cultivation means that the plant is assured of a suitable habitat, then, once it has developed, the conditions are kept suitable,

artificially by man, so far as he is able. For example, soils are manured, they are ploughed, hoed and harrowed, and water is supplied when there is insufficient rain. It is not so easy to supply suitable temperatures outside, but it can be done in the greenhouse; and even soil temperatures are controlled in some cases, such as in mushroom cultivation, by heating the soil by electricity or steam pipes. Light intensity, too, is not easily controlled, though in the case of some valuable plants this is done by a system of artificial electric lighting. In controlling conditions, man has been able to make plants grow in situations which otherwise would be unsuitable for them.

In Nature, such conditions cannot be controlled. Therefore we find that certain plants are suited to one type of habitat, but not to another, and vice versa. The study of naturally growing plants with relation to their environment is called **ecology**.

Mesophytes

There are some plants which definitely change their mode of life and structure in order to adapt themselves to an exceptional environment. The majority of plants, however, do not definitely change their structure, but, for some reason or other, prefer one habitat to another. Before studying the various habitats of the more normal plants (which are called **mesophytes**), a few of the specially adapted plants are worthy of attention.

Epiphytes

Some plants, instead of growing on the soil, that is, instead of leading a **terrestrial** mode of life, grow on the branches and in the axils of trees, and on palings, gates, dry walls, etc., thus being completely raised above the soil. Plants which grow on trees in this way are said to be **arboreal**.

Such plants are termed **epiphytes**. In Great Britain and other temperate countries, epiphytes are represented only by certain Algæ, such as *Protococcus* on the bark of trees, many lichens and some mosses. It must be remembered that epiphytes are not parasites, like the mistletoe, for they only treat the tree, etc., as a support, and not as a source of nutrition.

In tropical countries, especially in the luxuriant vegetation of the jungle, many flowering plants are epiphytic. Many orchids are (Fig. 43). They cling to the supporting branch of the tree by means of short roots which twine round it. Many of these plants have special methods of collecting water. The commonest one is by means of long aerial roots (see Chap. VIII). In the Tropical House at the Royal Botanic Gardens at Kew, many of these long aerial roots can be seen suspended from the epiphytic plants growing on the tropical trees there. The necessary mineral salts are usually obtained by epiphytic plants from the humus of dead leaves which collects round them. One very interesting epiphytic tropical fern is that called *Dischidia rafflesiana*. In this plant, some of the leaves are normal foliage leaves; whereas other leaves form pitchers. Into these pitchers the water given off by transpiration (and this *is* given off, since the pitcher is a modified leaf, which is the chief organ of transpiration) is condensed, and collects as liquid water in the pitcher. Down into this pitcher a branching root of the same plant grows, and is thus able to absorb the condensed water. It is also able to obtain a certain amount of nitrogenous matter, since these pitchers harbour ants which, when they die, supply a nitrogenous humus.

Xerophytes

Xerophytes are those plants which have specially adapted themselves to growth in habitats where water is very scarce. The majority of desert plants, such as cacti, are xerophytic. Pine trees also are subjected to physiologically xerophytic conditions, since the water supply is often frozen and then unavailable. The various methods of adaptation, both with regard to the storage of water and the prevention of excess transpiration, have already been examined (Chap. XII).

Hydrophytes

Special peculiarities in structure are found in plants which grow in water (called **hydrophytes**). The majority of them, such as the bladderwort and water milfoil, are able to absorb water all over their surfaces. The required gases, oxygen and carbon di-

oxide, are absorbed from the surrounding water in solution, just as in the case of seaweeds, etc., which are submerged in the sea.

Many hydrophytes have their leaves floating on the surface of the water, such as in the case of the water-lily (Fig. 321) and *Potamogeton*. The adaptation of the leaves to this habit, especially with regard to the position of the stomates, has already been considered. Plants with floating leaves absorb and give off their necessary gases in the gaseous state, and not dissolved

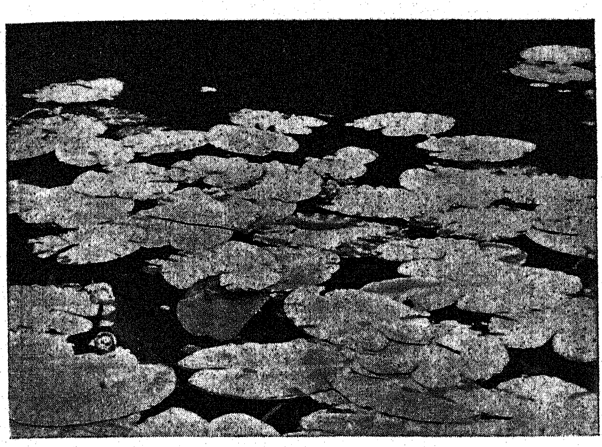


FIG. 321. YELLOW WATER-LILY.
(*Photo. Henry Irving.*)

in water. Therefore their stomates must be in contact with the atmosphere. That is why they are on the upper surface of the leaf. But such leaves run the risk of being flooded with water, especially when the level of the lake or river rises. Certain adaptations are sometimes utilised to prevent this. For example, the floating leaves of *Potamogeton* have very long stems which thus allow for changes in water level. The petioles of the floating leaves of certain tropical hydrophytes are shaped like a cork-screw, and therefore, in order to remain floating, stretch or contract according to the rise or fall in water-level.

A very exceptional type is seen in the tremendous leaves of the tropical hydrophyte, *Victoria regia*, from the Amazon. This

plant is often cultivated in botanic gardens. There is a special *Victoria regia* house at the Royal Botanic Gardens, Kew, where the plant can be seen. It can only be seen at certain times of the year, since it is an annual. In this case, the floating leaves are so large as to be able to support a baby. Flooding over the top of the leaf is prevented by a vertically growing margin, which is 2 to 3 inches high, thus making the leaf look like a floating tray (Fig. 322).

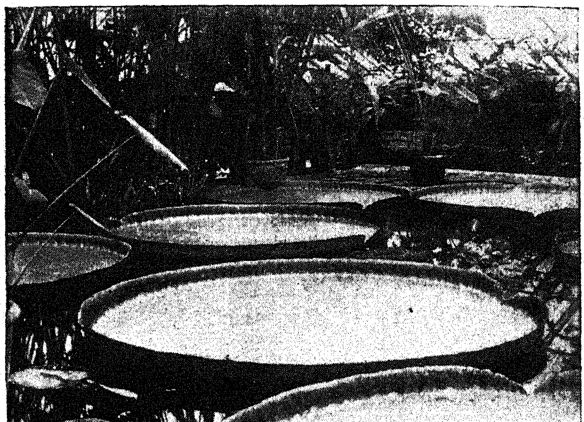


FIG. 322. *Victoria regia,* SHOWING THE LARGE LEAVES WITH UPCURVED MARGINS.

Certain hydrophytes grow in shallow water, in which case some leaves grow below the surface of the water, whereas others grow upright above it. The latter are in normal conditions, and therefore normal in structure. The former, on the other hand, are modified according to their submerged position. For example, stomates would be useless to them, so they have none. Also, they have to cope with the currents of water which might easily tear them. How completely submerged leaves adapt themselves to this contingency we saw in the case of the bladderwort in Chap. XV. In this case, the leaves become finely divided. In the case of plants with submerged leaves and also leaves above water, the submerged ones *only* become divided.

Thus, in such plants, there are two types of foliage leaves in one and the same plant. Two common examples of this in Great

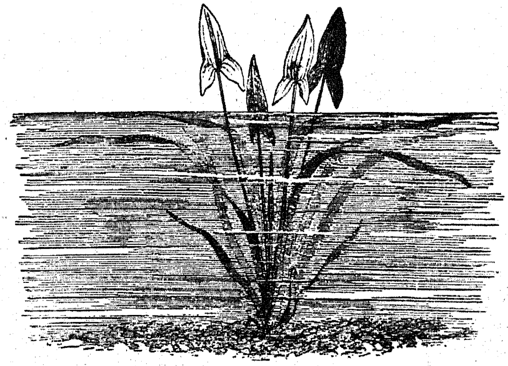


FIG. 323. ARROWHEAD, WITH ARROW-SHAPED AERIAL LEAVES, AND RIBBON-SHAPED SUBMERGED LEAVES.
(*After Figuier.*)

Britain are the arrowhead (*Sagittaria sagittifolia*) (Fig. 323), with upright leaves bearing an arrow-shaped petiole and sub-

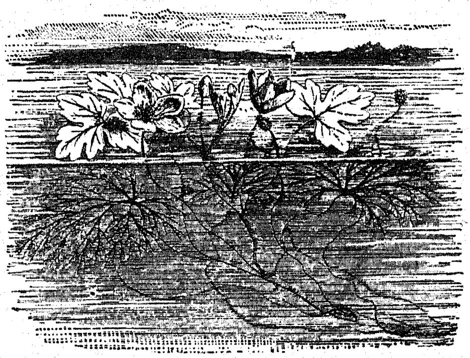


FIG. 324. WATER CROWFOOT, WITH LOBED FLOATING LEAVES AND FILAMENTOUS SUBMERGED LEAVES.
(*After Figuier.*)

merged leaves, long and ribbon-shaped; and the water crowfoot (*Ranunculus aquatilis*) (Fig. 324), with lobed upright leaves and finely divided submerged leaves.

Owing to the difficulty that hydrophytes experience in obtaining air for respiratory purposes, the tissues of the stems, roots and leaves often become full of very large intercellular spaces, usually in the cortex of the stem and roots. These large intercellular spaces act as air chambers, and such aerated tissue is usually called **aerenchyma.** Such tissue is common in the petioles of the water-lily, *Potamogeton,* and marestail (Fig. 325).

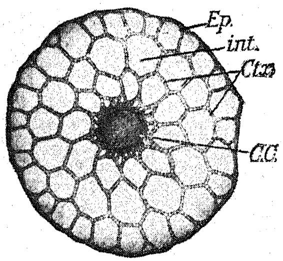


FIG. 325. PHOTOMICROGRAPH OF TRANSVERSE SECTION OF MARESTAIL.

Ep., epidermis; *Ctx.*, cells of cortex; *int.*, intercellular air space in cortex; *C.C.*, central cylinder ($\times 2\frac{1}{2}$).
(*T. D. T. Hall.*)

Plants growing in swamps may be considered as semi-hydrophytes, since their roots are subjected to water-logged conditions. Many such plants produce respiratory roots, which grow up into the air (Chap. VIII) in order to allow gaseous exchange. Such respiratory roots are clearly unusual in being *negatively* geotropic.

Halophytes

Quite a number of flowering plants are capable of living near the coast where the soil is periodically swamped with sea-water, and several flowering plants are capable of growing in shallow sea-water. Such plants, thus adapted to salt water, are called **halophytes.** Between high-tide mark and the sand dunes further inland may be found the sea rocket, saltwort (Fig. 326), etc.; all are halophytes with succulent leaves. Further towards the sea, where the soil is constantly saturated with sea-water, may be found the glasswort, which has very minute leaves but thick, fleshy, jointed stems. The reason why such halophytes bear succulent organs is that the high concentration of the sea-water makes osmosis very difficult. Thus, such plants have to store what water they can get. The branched stems of the glasswort can absorb dew and rain-water readily.

Of the utmost value to man are certain halophytic grasses. These are capable of growing in salt marshes, and they grow so

prolifically that finally the marshes become dried up, and their levels raised, owing to the tremendous activity of the plants in forming humus from their own dead bodies. In Europe, one halophytic grass called *Spartina stricta* occurs in the salt flats of southern England, and in the Mediterranean coasts. In the salt marshes around Southampton is another called *Spartina alterniflora*, where it was introduced by ships from America. There it is colonising the marshes so much, that certain parts around Southampton, which were once marshes, are now dry land.

The most efficient halophyte in colonising salt marshes is the rice grass, *Spartina Townsendii*. This halophyte originally grew around Southampton, but now it has spread along the mud flats of the southern coast, and is choking up certain parts of Poole harbour, in Dorset. Rice grass is being used for reclamation of new land from the sea. This is the case in Holland, where, since 1924, when the plant was definitely introduced for the purpose, it has grown so prolifically, that acres of land, previously salt marshes or actually under the sea, have been reclaimed and now used for agricultural purposes. The rice plant is doubly useful in this respect, since not only will it help in speeding up the process of land reclamation for agriculture, but it is also a good food itself for farm animals.

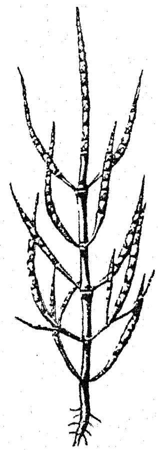


FIG. 326. SALTWORT, A CHARACTERISTIC HALOPHYTE.

Competition and Colonisation

The study of the social life of plants can be made a very extensive one, taking in the examination of the distribution and inter-relationships of plants throughout the world, or it may be a very intensive one, merely involving certain well-defined areas. The extensive study is referred to as **plant geography**, whereas plant ecology involves a detailed study of definite, small areas.

One very important thing to realise is that plants in their wild or native state have scarcely any choice in their home or habitat. In this they differ from cultivated plants. The former have to trust to chance in finding a suitable home ; the latter have a suitable home made for them.

It stands to reason that on any one piece of ground, thousands of plant seeds must fall in a year, yet it is clear that only a few actually take to the soil and grow. If it is a barren, infertile soil, with poor particles, a low mineral content, bad exposure and unsuitable climate, few plants will succeed. Thus, with regard to the invasion of soil by seeds, " many are called but few are chosen." The rest of the seeds perish. Thus is there great mortality in the plant kingdom every day.

One excellent method of studying colonisation by plants, is to watch the gradual invasion of a newly exposed piece of soil. Of course, in Great Britain, this is not very easy ; yet one can get a great deal of information concerning the colonisation of plants by studying the newly made banks of roads and railway cuttings. The study may extend over several seasons, and the type of plant, the time that it arrives, the percentage of different plants, etc., duly noted.

In such cases, plants which develop quickly from spores, and not seeds, are the first arrivals. Spores are produced by many of the simpler types of plants, such as Algæ, Fungi, mosses, liverworts and ferns. These usually arrive first, since spores are very small—microscopic, in fact—and are easily carried in the air. Next come the ephemeral and annual flowering plants common to the neighbourhood. A community of plants thus produced is still not very closely packed and, since it has no definitely established perennials, it is still open to newcomers. It is therefore called an **open** community.

Then along come more hardy perennials such as certain grasses, thistles, plantains, dandelions, etc., and competition is set up between the plants, because, by now, the community is becoming overcrowded. Then the weaker plants are choked out and die, and the hardier ones become more firmly established. Finally, only those plants which are suited to that soil and climate remain, and then the community is said to be **closed.**

Such a closed community of plants living quite in harmony with each other, allowing only those newcomers which can compete with them to remain, and choking out any newcomers that cannot compete, or are otherwise unsuited, is then called a **plant association.**

Thus plants fight amongst themselves for a place in the sun. But there is also competition among their roots for a place in the soil. It is amazing sometimes how far the roots of trees will penetrate the soil ; some roots go down more feet than the topmost shoots are high. The root competition is chiefly due to the search for an adequate water supply.

It has been shown experimentally that apple trees planted 40 feet apart yielded 43 bushels more fruit to the acre than trees planted 30 feet apart. This is interesting from the point of view of plant accommodation in both air and soil.

Plant Associations

There are many types of closed communities of plants, or plant associations, in Great Britain. Several associations are very often found together, bound by some common bond of habit and habitat. For example, a sand dune, salt marsh, moor, etc., each have their collection of plant associations. Such a collection of associations is called a **plant formation.**

The examination of a plant formation and its constituent associations makes interesting study. The most valuable information concerning this branch of plant ecology in Great Britain has been contributed by **Professor R. H. Yapp** and also by **Professor A. G. Tansley** and **Professor E. J. Salisbury.**

There are several methods of study. One is to examine a rather large area. Then obtain a blank map and shade in with various colours the different types of vegetation, such as woodland, scrub, meadow, hedgerows, moor, marsh, water, cultivated land, etc. Then this should be correlated with the physiography, the geological formations, the weather and types of animals, etc., all of which have certain effects.

A more intensive study is that referred to as the **quadrat chart** method. This can only be applied to a much smaller area. In this case a rectangular area is marked out on the land by tapes.

This is then divided into smaller squares by tapes or string, then the whole thing represented on squared paper.

A more picturesque method applicable especially to a hedgerow, edge of a wood, river bank, etc., is that called the **transect method.** This involves drawing a section through the habitat to be examined, then representing the various types of plants along the section.

It must be remembered that no plant association or formation is absolutely stable. There are certain factors which decide what type of plant shall constitute it in the first place, such as nature of the soil, climate, etc. ; but then there are other factors such as disease epidemics, useful and harmful animals, which come along afterwards and modify it.

Such factors are so numerous that it would be difficult to name them all. Also, whereas one certain factor may be very potent in one plant formation, it may be entirely absent in another. However, certain factors are rather general. **Climatic** factors, for example, are very important. These comprise chiefly conditions of moisture, temperature and light. **Physiographic** factors depend upon the shape of the country, mountainous or flat, etc. The chemical and physical nature of the soil form certain very important factors for several clear reasons. Such factors associated with the soil are called **edaphic** factors. Finally, a very potent factor in nearly all cases is the **biotic** factor. This involves the influence of other forms of life, plant and animal. For example, a beech tree casts a very dense shade. The result is that in beech woods very little ground vegetation may be found. Therefore the beech trees are a biotic factor. Many animals form a biotic factor. Some give manure and therefore form a useful biotic factor ; others eat the plants of the formation and are thus a harmful one. Man himself is a biotic factor even where wild plants are concerned. This is well seen in the forests where lumbering goes on.

It is impossible to study all plant associations, therefore one is always well advised to examine those within easy reach. A written description of any type of plant association can, of course, be no more than a guide to practical study. There is little to be gained from merely reading about such things, and very little

interest. On the other hand, to get out into the country with notebook and drawing book holds an almost indescribable fascination, which no amount of reading can supplant. It is proposed, therefore, merely to give a brief idea of the nature of the most easily available plant associations and formations, and to leave anyone interested to get the fundamental information by his own practical efforts.

First, it is quite clear that in no plant association is there an equal quantity or distribution of plants. Also, the plant members of any one association do not all develop at the same time. Thus, in examining an association, several studies should be made at different times of the year. First of all one should begin with a note of the type of country. Dates when examined should be stated, and a detailed study of the factors, especially edaphic and climatic, should be made. At all times the ratio and distribution of plants within the association should be thoroughly investigated.

For example, one, two or perhaps even three plants form the most important members of a plant association. These are called the **dominant** plants. The dominants very often help to answer the question of why are the others such as they are, for dominants are often biotic factors to the other members of the association. This may be seen in a beech-wood association. Here, few herbs are found growing on the soil. Why this is can be answered by the dominant beech, for it is such a dense tree that it casts a shade and prevents light-loving plants from growing beneath it. Very often, closely associated with the dominant plants are others which are almost as common. They are then said to be **subdominant.** Less common again, but evenly distributed throughout the association, are other plants. These are said to be **distributed.** Much less common again are those plants said to be **occasional,** and the sparsest of all are classified as **rare.**

Woodlands

Very familiar plant associations in Great Britain are the **woods.** There are several types of wood associations in this country. In the highest altitudes are wood associations with

pine or birch as the dominant plants. At lower levels are two types, depending chiefly on the type of soil. On the lower hills with a sandy soil are the dry oak woods, whereas on a clayey soil are the damp oak woods, containing many hazel trees as subdominants. On the limy soils at the same levels are beech woods and the ash woods. On the plains, that is, the lowest levels of all, the woods are chiefly a mixture of oak and ash, whereas on

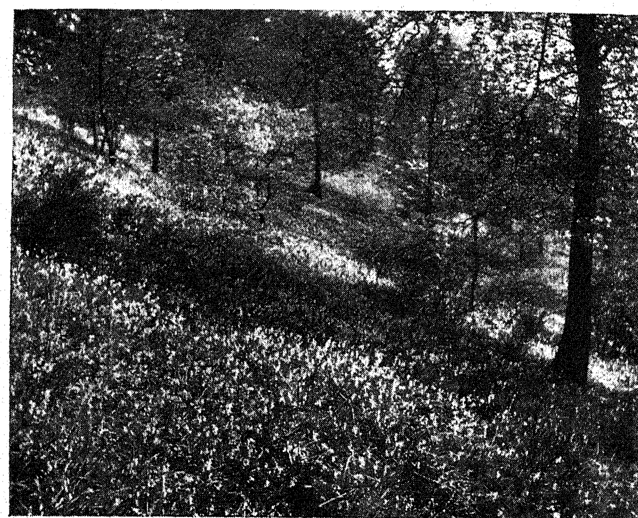


FIG. 327. OAK WOOD IN SPRING.
The surface is a carpet of bluebells, and the grass is soft-grass.
(Photo. W. B. Crump.)

the very damp soils at such levels the woods are smaller, being composed chiefly of alder and willow.

In all the cases of wood associations mentioned, the trees form the dominant plants. They act as biotic factors in different ways so that each type of association has its special subdominant, distributed, occasional and rare plants. For example, the beech wood is very dense, but usually well manured with the humus formed of fallen leaves. Subdominant on its edges is the bluebell. Distributed throughout is the bird's nest orchis, a

saprophytic flowering plant which clearly will not suffer from the dense shade. In the dry oak wood, high up on the hills, subdominants are gorse, ling and bracken. In the dry oak wood of

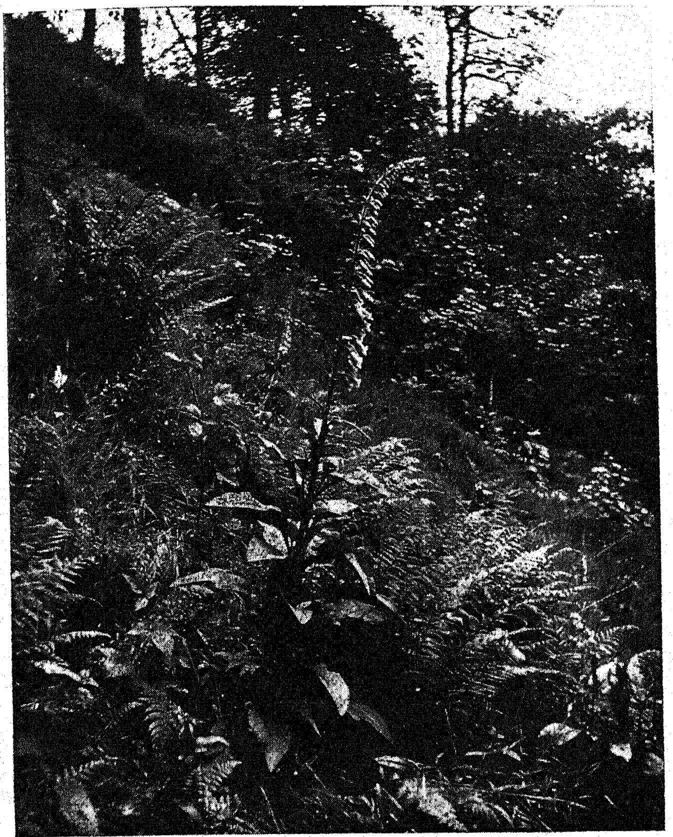


FIG. 328. OAK WOOD IN SUMMER.
The subdominants are foxglove, male fern, lady fern and soft-grass.
(Photo. W. B. Crump.)

lower levels, the subdominants are holly, anemone and bluebell, with the foxglove well distributed (Figs. 327 and 328). The damp oak wood is much more shaded and the herbaceous

undergrowth is represented best by wood sorrel (Fig. 329), wood geranium, violet, woodruff, etc.

Hedgerows

The **hedgerow** forms a very interesting plant formation, since there are several levels to examine, comprising chiefly the hedge itself and the bank. The hedge itself varies in different parts,

FIG. 329. WOOD SORREL, A SHADE-LOVING PLANT.
(*Photo. Henry Irving.*)

being composed of some, or all, of the following: hawthorn, hazel, maple, bramble, blackthorn, willow, holly, etc. The bank of the hedge shows more variations. At the top are plants which have to contend with a certain amount of shade. These may be climbers which can scramble to the light, such as the bramble, wild rose, clematis, goosegrass (Fig. 330), bindweed, honeysuckle, bryony (Fig. 331), and various vetches. They have different means of climbing, which are worthy of study. Other plants which can fight the shade of the top of the bank are those

with very long, erect stems, such as stinging nettle, deadnettle, certain grasses, hedge mustard, garlic mustard, stitchwort, etc. Finally, there may be plants which prefer the shade, such as certain ferns, garlic, wild arum, enchanter's nightshade, foxglove, primrose, ground-ivy, germander speedwell, sweet and dog violet and a host of others.

On the slope of the bank the light is abundant. Here, therefore, we find prostrate plants such as creeping buttercup, wild strawberry, etc., and rosette plants such as daisy, dandelion, plantain, etc. For obvious reasons, the vegetation of a hedgerow is very similar to the intermediate plant association found at the edge of a wood.

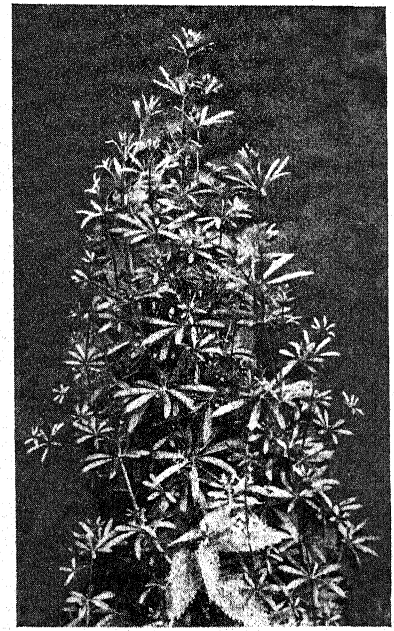


FIG. 330. GOOSEGRASS, CLIMBING UP NETTLES IN A HEDGE.
(*Photo. Henry Irving.*)

Meadows

In the majority of **meadow** associations the dominants are usually grasses, such as perennial rye grass (Fig. 332), meadow fantail (Fig. 333), and meadow fescue, together with white clover (Fig. 334). In various meadows, certain subdominants may be found according to the soil structure and composition. These may be daisy, buttercup, cowslip, sorrel, ox-eye (or moon) daisy, etc.

Lawns and **arable land** are associations closely related to meadows, with the exception that in these the dominant plant or plants are cultivated. Usually, all other plants, subdominant, distributed, occasional or rare, in such associations, are **weeds.** A weed is any kind of plant which grows where it is not wanted or

is a nuisance. Many meadows have their weeds, since the meadows are required for the production of hay. Any plant growing in such a meadow which will spoil the hay is therefore a weed. Such weeds are chiefly the ox-eye daisy, sorrel, bitter buttercup, thistle, etc.

G. 331. HAWTHORN HEDGE COVERED WITH BLACK BRYONY AND BRAMBLE.
(*Photo. Henry Irving.*)

On cultivated lawns the dominants are various grasses. The most troublesome weeds of such associations are the rosette plants such as dandelion, daisy and plantain. · The yarrow and creeping buttercup also form troublesome occasionals. On cultivated arable land, the weeds are all too familiar to the farmer and gardener. In gardens, the chief are groundsel, lesser bindweed, chickweed, thistles, and dandelion. In cornfields they are the same at the early stages of cultivation. Later, along come

the charlock and crowfoot, and later still, the poppy and corn-cockle.

The eradication of weeds is still done chiefly with hand and hoe. Sometimes poisonous chemicals are used. Then in certain cases, spraying is resorted to. For example, stinging nettles can be got rid of from meadows by spraying with a 1 per cent solution of sodium chlorate. Another simple method of getting rid of the same weed, recently recommended to farmers by the Ministry of Agriculture, is to place a feeding trough or rock-salt lick in the middle of the nettles. In getting at these, cattle trample down the troublesome nettles very efficiently.

FIG. 332. PERENNIAL RYE GRASS.
(Copyright, Sutton and Sons.)

Aquatic and Semi-Aquatic Associations

Marshes, ponds and streams have very characteristic plant associations. The diagnostic features of some of these plants have already been examined with relation to their hydrophytic habit.

In a marsh (Fig. 335) the soil only is water-logged, therefore only the roots and rhizomes of the plants are affected by the excess water. In some marshes the dominant is the osier willow, whereas in others it is the rush. Subdominant and distributed include burweed, meadowsweet, ragged robin, wild iris (flag), marsh marigold, marshmallow, water mint, water forget-me-not, etc.

Between the marsh and the pond or stream proper, comes an intermediate formation, commonly called the marginal

association. This formation can often be divided into three zones or associations, which merge into each other, provided the slope of the land towards the open water is a gentle one. The first zone is that nearest dry land. Here, only the roots are subjected to water-logged conditions. The members of this zone are similar to those of the marsh, together with others that are dominant or subdominant, such as reeds, bulrushes, common rushes, sedges, horsetails, watercress, etc. This shore association is often called a **reed-swamp** association.

FIG. 333. MEADOW FANTAIL.
(*Copyright, Sutton and Sons.*)

The next association is that intermediate between this reed-swamp association and the complete water association. In it, plants which are rooted in the soil, with parts of their stems submerged but leaves and flowers held above the water or floating on it, may be found. Such plants are the arrowhead, water crowfoot, *Potamogeton*, water-lily, etc.

In the third association, the plants are entirely submerged. The most common types found here are Canadian pondweed (*Elodea*) and tape grass (*Vallisneria*). *Elodea* is of particular interest owing to its prolific growth. It can reproduce itself by a very simple means of vegetative reproduction. Any small branch, if broken off, will reproduce a new plant. So prolific is this, that once *Elodea* establishes itself in a suitable pond, it soon chokes up the pond, unless it is periodically cleared out. That is why this plant is such a nuisance in water-works, etc. The great rate at which it can vegetatively reproduce itself can

be realised when one knows that before 1841 it was quite unknown in England. Now it is one of the most common and prolific water plants throughout the country, and also Scotland and Wales. Actually it is a native of North America and Canada (hence its full name of *Elodea canadensis*). Then it was

FIG. 334. WHITE CLOVER, A GOOD FODDER PLANT.
(*Photo. Henry Irving.*)

mysteriously introduced into Co. Down in Ireland in 1836 and in England in 1841. To-day it is common in nearly every lake pond, stream and ditch of the islands.

Heaths and Moorlands

The **heath** association may be found on moorlands, especially in Scotland, Yorkshire, Lancashire, and certain parts of Devon, Somerset, Kent, etc. The dominant is the ling (commonly called heather). In Scotland, other dominants are the true, or bell, heather, the bilberry and (in certain parts) the cross-leaved heath. Most heath plants are much exposed and therefore have

certain xerophytic adaptations. The heather, for example, has rolled leaves. A local subdominant is the gorse which, as we have already seen, is xerophytic. Other local dominants are the mat grass and bracken (Fig. 336). Occasionals are represented by the pine.

FIG. 335. A TYPICAL MARSH.
This contains branched burweed, osier willow, marsh stachys, mint, forget-me-not, willow herb, polygonum and grasses.

Real moorland associations differ from the heath in that they have a great deal of peat in the soil, which is usually very acid. Peat is formed chiefly by the accumulation through hundreds of years of *Sphagnum*, the peat moss, common in certain parts of Somerset and especially in Ireland. The dried peat forms a kind of fuel. Higher up, wet moorland associations often have cotton grass (which is not really a grass) as the dominant. This cotton grass association can be found in the higher moors of Yorkshire and on Exmoor (Somerset and Devon) and Dartmoor (Devon) (Fig. 337).

The very low-lying moors contain not only peat but also much water and are very acid. Here may be found certain insectivorous plants such as the sundew, butterwort and, in the free water, bladderwort. This is because such acid peaty soils are deficient in nitrogen compounds.

FIG. 336. UPLAND HEATH.
(Photo. Flatters and Garnett, Ltd.)

The wet peat soils of the east of England, especially in Cambridgeshire and Norfolk, vary from this in that they are very rich in mineral salts, especially of calcium, and are therefore alkaline. They are commonly called **fens**, and the plant associations of the Fen District vary accordingly. The dominant tree is the alder. The Fen District of East Anglia, right up to and including the Wash, has been the subject of intensive drainage schemes ever since the time of the Roman invasion. Consequently, soil conditions, especially from the point of view of

water content, are constantly undergoing changing conditions. Thus has man become a very potent biotic factor in this area. The detailed ecological study of the area has therefore offered great opportunities for botanists and zoologists.

The first great study of the structure of the vegetation from the static, that is, unchanging, point of view was made by Pro-

FIG. 337. COTTON GRASS IN FRUIT IN A BOG.
(*Photo. Flatters and Garnett, Ltd.*)

fessor R. H. Yapp, in this country. But, with changes in conditions, great changes in the flora are taking place. New plants come, old-established ones disappear, dominants become rare, and rare become dominant. The study in the changing flora (dynamic ecology) has been initiated by Professor A. G. Tansley of Oxford and Dr. Godwin of Cambridge. So important is such an area to the plant and animal ecologists that one part of it, Wicken Fen in Cambridgeshire, has been purchased for the nation by the National Trust. Thus has it been secured, for all time, for further studies in ecology.

Sand-Dunes

An important plant formation is that of the **sand-dune**, so common around our seashores. Here, conditions are very exceptional. The almost pure sandy soil is very loose and consequently abnormally dry. The surface is exposed to bright light, heat and all types of wind. Therefore, transpiration can take place at an

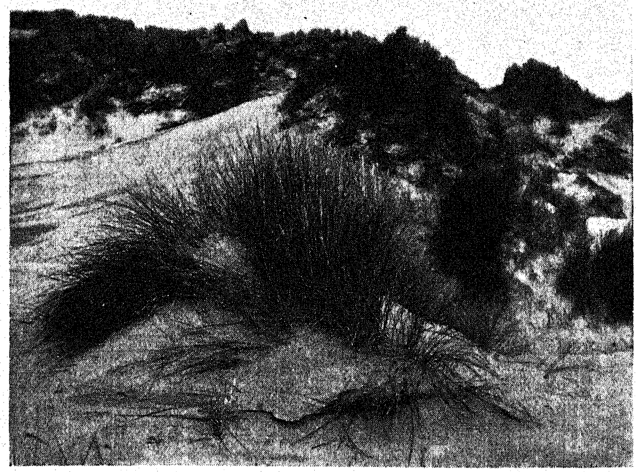


Fig. 338. Marram Grass growing on the Crest of a Sand-Dune.
(Photo. W. B. Crump.)

abnormally high rate. But a sand-dune has several aspects, thus giving several associations.

There is the surface sloping towards the sea. Here the sand is loose and drifting. The dominant plants are not very thick, and many bare patches of sand are exposed. The chief is the sea couch-grass which has long rhizomes which help to bind the sand together and thus reduce drifting.

The next association is that on the top of the dune. Here the sand is still loose and constantly shifting, but not so much as in the previous case, since the rhizomes of the sea couch-grass

association help to prevent it. The dominant here is the marram grass which thus gives a marram-grass association (Fig. 338).

The third association of the sand-dune formation is that on the side sloping away from the sea. Here the oldest parts of the dunes (which is formed by sand blowing up from the seashore) may be found. The sand is much more firmly set. Here the dominant is the creeping willow, and the association is named after it. Distributed and occasional plants are represented by bird's-foot trefoil, rest harrow, thyme and stonecrop.

In the plant formations and associations described above, no attempt has been made to give exhaustive lists of plants, dominant, subdominant, distributed, occasional or rare. Such lists would convey very little to the reader, and would scarcely serve any useful purpose. An open-air study of whatever formations or associations are within reach is, however, highly recommended.

CHAPTER XXIV

EVOLUTION, BREEDING AND CLASSIFICATION

The Planet Earth

THE planet Earth, on which we and other creatures and also plants live, is millions of years old. Exactly how old the Earth is we cannot say, but we do know that it runs into a vast number of years. How the Earth originated is still a matter of conjecture, yet one thing is practically certain and that is, for many millions of years after it became a separate body in space life was quite impossible on it. The Earth, when it was first formed, was nothing like it is to-day. Exactly what state it was in is also another unsettled problem ; but most probably it was a molten mass. Therefore until such a mass had cooled down, life was clearly impossible on it.

Origin of Life

Life on the earth became possible in early geological times. This we know for certain, from a study of the rocks of the earth, which vary in age. In these rocks have been found, and still are being found, fossilised remains of plants and animals. These remains, scanty though they are for giving us a real conception of what life was like on the earth throughout the ages, have already told a remarkable story. The chief lesson we have learned from them is that several millions of years ago, plant and animal life was totally different from what it is to-day. Man and flowering plants, for example, did not exist in those far-off ages. A long time before that again, animal and plant life was totally different. In other words, when the earth is taken at various stages of its existence, each stage separated by several millions of years, life, both plant and animal, is seen to be totally different. The changes in such life most probably did not

come about suddenly, but very gradually, almost imperceptibly in fact ; and there is no reason for believing that changes in plant and animal life are still not taking place, with the result that in many millions of years to come, plant and animal life on this earth will be totally different again from what it is to-day.

If this is the case, one might ask : Why do we not see such changes going on now ? Why are plants and animals more or less the same when we are seventy years old as they were when we were seven ? This is easily answered in that the change is so very, very slow, that no perceptible change takes place in one man's lifetime. It is just like looking at the two hands of a clock. If the minute hand is carefully watched, it can be seen to move very slowly ; yet we cannot see the hour hand moving. But we know that it does, for at the end of an hour it points in a slightly different direction. The changes in living things that have taken place for the past millions of years, that are taking place now, and that will continue to take place for many millions of years to come (probably until the earth itself finally comes to an end), are like the hour hand of the clock. To look at them, we can see no change ; but to look at them after certain periods have elapsed (millions of years in this case), we see definite alterations.

Before considering the changes going on in life, it will be worth while to consider the very beginning of life on the earth. We are quite certain that life was impossible on the earth when it first came into being ; therefore life must have begun at some definite time. So, how did life begin on the earth ? What is the origin of life ? Perhaps we shall never be able to answer these questions for certain. But, in spite of this, it does not follow that we shall never be able to get a moderately good idea of life's origin. When we know more, we may be able to settle the question. On the other hand, we may not ; but it would be a very daring person who would say that we never shall.

From observations of life as it is to-day, several theories of its origin have been put forward. Some are reasonable, others are extravagant ; but all are of interest.

At one time many men of science, including the late **Lord Kelvin**, the great physicist, believed that life was never formed

on the earth but that it has come upon it from outside the earth in the form of minute organisms, similar to bacteria, present in the crevices of meteorite and other cosmic substances which periodically fall upon the earth from outer space. Even to-day some people hold this idea and now and then one reads of a man of science examining meteors and finding living bacteria inside them. Perhaps this is true, but it does not follow that life therefore originated upon the earth in this way. Also, even if the whole conception were true, it would only shift the problem a little, for we should still want to know how life originated in the meteors, or even in the structures from which meteors come.

The theory propounded by **Aristotle** was that of spontaneous generation, which has been considered in Chap. XIV. Strange to say, the idea of spontaneous generation, at any rate in the more lowly plants and animals, was held for nearly a thousand years—that is, until the seventeenth century—when, with the advent of the microscope, it was brought into question, but not completely refuted until the work of Pasteur made it certain, in the nineteenth century.

The theory held by most people of to-day is that living matter has been built up by a mysterious natural process of synthesis from non-living material. It is not very difficult to conceive of this possibility. All we want to know is, how did any kind of living matter come into being? At present, we are not concerned with advanced living things like man and flowering plants. We already know that the fundamental basis of life is protoplasm. This was emphasised by **T. H. Huxley**, the great biologist of the nineteenth century. If we could get to the bottom of the origin of this substance, then we have settled the origin of life. What went on afterwards is a different problem.

We have already learned that protoplasm is a very complex mixture of crystalloids and colloids, especially proteins. Now, already, certain carbohydrates have been synthesised in the chemical laboratory from simple, inorganic substances. So also have amino acids; and these are closely related to the proteins. This shows that it is not impossible that all the constituents of protoplasm can be built up from simpler substances, substances which already exist on the earth and the waters on the earth, in

the non-living, inorganic state. This is probably what took place. The compounds got together, and in a mysterious manner formed the crystalloids and colloids essential to protoplasm. This took place in water where the raw materials were present. Thus was protoplasm possibly built up in the first place, and there lies the possibility of the origin of life. If this be so, then all life has originated in water, possibly the sea.

We have much evidence of this to-day, and feel practically sure in stating that all life began in the sea, and there it remained for millions of years. Then it began invading the land. First we had these forms which still depended upon water for certain parts of their existence. These are called amphibians. There are many examples of amphibious animals and plants with us to-day. The frog, for example, is amphibious. It can live in water and on land, but only marshy land. Its eggs must be laid in water, and the young tadpoles must live in water for they can only breath air by means of gills, like a fish. Finally in the adult stages, the animal can live on land and breath air, in the gaseous form, by means of lungs like the more advanced animals which have completely invaded the land (terrestrial animals).

In the plant kingdom, mosses and ferns are more or less amphibious. Most of them prefer very damp situations, yet in their complicated method of reproduction, at one part of the process they must have very dry conditions, just as the stamens of the terrestrial flowering plant must have dry conditions in order to burst. In the other part of the reproduction of the fern, that is, actual fertilisation, it must have liquid water, for the only means of the sperm getting to the egg is by swimming through liquid water. This it does by lashing its numerous cilia (Chap. XXII).

Evolution of Life

Life clearly did not *suddenly* originate in its thousands of different forms, simple and complex, as we know them to-day. It began in a very simple form, and then throughout the millions of years it has undergone changes; very slowly, of course. Original life knew no distinction between plants and animals. After many millions of years, as life went on developing its

various types, plants developed along one channel and animals along another. Thus we have the various types of plants and animals of to-day. As development went on throughout the ages, all forms of life became more and more complex.

The first types of plants were possibly Algæ, all living in the sea. Then these gradually moved up the fresh-water rivers, giving the fresh-water Algæ. Then plants began to invade the land. The first types resulting from the change in mode of life were possibly the liverworts, closely followed by the mosses. Then came the ferns. Gradually, after the establishment of these amphibians, through millions and millions of years, real terrestrial plants began to develop. The first were possibly the gymnosperms and these were followed by simple types of angiosperms, something like the magnolia flowers of to-day; for although the flower of magnolia is comparatively large, it is of an exceedingly simple structure, simpler even than that of the buttercup. Then, once established, more complicated flowering plants began to develop, thus giving us the many thousands of species of flowering plants on the earth to-day. Possibly the most advanced in this great development scheme are flowers like the daisy and dandelion. Being the most advanced they are therefore the youngest, considering the complete age of plant life.

Origin of Species

This theory of the development of life from a simple origin to its present-day advanced state is referred to as the theory of **evolution**. Though it had been suggested before, it was first of all clearly formulated by the great naturalist, Charles Darwin, to whom we have already been introduced in our studies in plant life. Darwin took many years to formulate this stimulating theory; but the idea began to grow in his mind while voyaging on the *Beagle* (see Chap. XV). Finally he published it in a famous book called the "Origin of Species by Means of Natural Selection," which appeared in London for the first time in 1859. Darwin's idea of the origin of plant and animal species was received with great acclamation by some, consternation by others, and resentment by many. To-day, few people disagree with his fundamental ideas, though many differ from him in

certain details. It was through his "Origin of Species" that Darwin's name has become immortalised.

The theory of the origin of species was an epoch-making incident. The whole idea completely changed the outlook of biologists, and, having accepted it, their progress in the search for new knowledge of plants and animals was increased a thousandfold.

But Darwin's idea of the origin of species was not propounded merely to explain the development of plant and animal life throughout the ages of the earth. It is a matter of common observation that plants and animals differ within themselves greatly, yet, though many differ from each other, others resemble each other. For example, a cat differs considerably from an elephant, yet it closely resembles a tiger. A primrose differs very much from a violet, yet it is very like a cowslip.

Plants and animals can therefore be classified according to the degree in which they resemble or differ from each other. The classification of plants will be considered later; but a general consideration is necessary in order to appreciate Darwin's work. For example, two primroses, though they may be slightly different from each other in, say, size, are very like each other generally. So are two cowslips. Yet a cowslip and a primrose differ from each other much more, though there is still a resemblance. Then a primrose and a bluebell differ even more; a primrose and a fern still more, and so on. All plants closely resembling each other are placed in a single group called a **species.** Primroses all over the world belong to the same species; all bluebells also belong to the same species, a species differing very much from the primrose species. Darwin, in his "Origin of Species," attempted not only to explain the evolution of plants and animals from the lowest forms to the highest; but also why members of the same species are so much alike and members of different species are so different.

There is no doubt that from the earliest times, man must have speculated on the nature and origin of the multitudes of various living things around him. **Erasmus Darwin**, who was born in 1731, and was the grandfather of the illustrious Charles Darwin, suggested a kind of evolution of life, and the great French

naturalist, **Jean Baptiste Lamarck,** also discussed the possibility of evolution. But the whole question was still very much in the melting-pot of conjecture until Charles Darwin himself came along with his brilliant work in 1859. The whole idea of Darwin's—that is, of the gradual transformation of simple living things into the more complex things—was one of the greatest triumphs of modern science. This is chiefly because it has completely revolutionised the various sciences of life, including zoology, botany, medicine and psychology (the study of animal behaviour). At the time, it met with much opposition, but eventually it won through, and its fundamental truths hold the field to-day.

Fossil Plants

Having many of the lowly organisms with us still, it should be possible to trace the gradual change, that is, the evolution, from the lowest forms to the most advanced. Yet, strange though it may seem, this is not altogether possible. Up to a point we can trace a gradual sequence of events that most probably took place during this great process of evolution throughout the millions of years, yet the sequence is broken in certain places by definite gaps. But this does not prove that Darwin's idea of the evolution of life is all wrong. It may be compared with another very ingenious conception, in the science of chemistry. There is a well-known law in chemistry known as the Periodic Law. This law was first postulated by the Russian chemist Mendeléeff. By this law, all the chemical elements can be arranged according to their atomic weights. By doing this, Mendeléeff found that there is a definite relation between them and their chemical properties. But in this arrangement he also found gaps. Yet he was not perturbed by this, but merely suggested that the gaps were due to elements which, up to that time, had not been discovered. So he imagined them there in his periodic table, and even suggested their nature and properties. In this, Mendeléeff has been proved correct, for, since his day (1834-1907), certain new elements have been discovered, and they not only fit in well where they should, according to his Periodic Law, but they also have the properties which he had prophesied for them.

The same may be said of the gaps in the evolution of plants and animals. That there are gaps, no one would doubt ; but so sure are scientific workers of the whole conception of evolution and the gradual change from one species to another, that they have been able to suggest the nature of those plants and animals which should fill the gaps. One might say that all this is conjecture, just a mere description of imaginary plants and animals to fit the case conveniently. But this is not so, for up to date quite a number of plants and animals have been discovered in the fossilised form, and, judging their ages by the rock strata in which they have been discovered, they have fitted into certain of the gaps of Darwin's evolutionary sequence. Not only have they fitted the gaps, but they also exhibit the structure which they should have according to the theory. Thus, fossils are a great support of Darwin's theory of evolution. There are still many more gaps to be filled in the sequence of events ; but it is quite likely that as time goes on, and scientific workers tackle the problem as they are doing to-day, some fossil plants will be discovered, somewhere in the world, to fill the still vacant gaps.

Much of the work on fossil plants which has helped considerably in the elucidation of the evolutionary sequence of plant life during the past has been carried out chiefly in Great Britain. One of the greatest fossil botanists was **Professor W. C. Williamson.** He did much work on plant fossils present in coal ; and although few people at the time took any notice of the results obtained, it is now realised how important they are from the point of view of evolution. Since Williamson's time, much work has been done on fossil plants, which are now treated chiefly as documentary evidence of the history of plants. Some such fossils are probably 500,000,000 years old. Other past workers in this field of botany were **Sir John W. Dawson,** who worked chiefly in Canada, and **Dr. R. Kidston,** formerly of the University of Glasgow, who worked chiefly on Scottish fossils and made some very important discoveries. A great deal of the fossil botany of America was worked out by **Dr. Lester Ward,** who, for some time, was the geologist to the United States Geological Survey.

By far the most of fossil botany known to-day has been carried

out during the present century. Now, all over the world, there are many scientific workers who are attacking the problems set by newly discovered fossil plants of all ages, and adding much to our store of knowledge of plant evolution of the past. In Great Britain the most recent work has been done by **Professor W. H. Lang, Professor A. C. Seward,** and **Dr. D. H. Scott.**

Struggle for Existence

The most important part of Darwin's theory of evolution concerns not so much the fact that plants and animals have undergone slow changes throughout the ages, from the very simple unicellular organisms living in the sea to the complex multicellular organisms as we know them to-day, but the methods whereby these gradual changes have taken place.

The whole principle of the Darwinian theory rests on the basis of the great idea of the survival of the fittest in the struggle for existence. This idea was conceived by Darwin in 1842 and again, quite independently, by the great travelling naturalist, **Alfred Russel Wallace,** in 1858 while he was travelling in the Moluccas. This idea, which we will examine before considering the further details of organic evolution, struck the men of science of the day so much with its ingenuity, that credit for the idea has always been given to both Darwin and Wallace jointly. In fact, at the suggestion of Sir Charles Lyell, the geologist, and Sir Joseph Hooker, the botanist, the remarkable conception was publicly announced under the joint names of the two naturalists.

There is scarcely any doubting the principle of the struggle for existence in all plants and animals living in their native state. This is because many more organisms are born into the world than can possibly live in it. It has already been seen that a single large mushroom fructification can produce 10,000,000 spores, every one of which is capable of producing a new mushroom plant. Other examples are just as convincing. A single female codfish may lay 9,000,000 eggs in one year. A single pair of carrion flies can produce 20,000 larvæ. These can hatch out into new flies in about a fortnight, and all these new flies can produce more larvæ amounting to 200,000,000 larvæ, thus giving

that number of grandchildren to the original pair. Multiplication in the plant and animal world is not purely arithmetic but geometric, thus giving tremendous numbers of possible offspring. Some bacteria have been calculated to produce millions of millions of offspring in a single day.

Thus there must be a great struggle amongst all living things to survive, for we know from mere observation that by far the majority of living things born into the world never survive. If they did, in less than a week every square inch of soil would be covered with mushrooms, the whole atmosphere would be choked out of existence by carrion flies in even a shorter time, and the sea would be so full of codfish that it would be possible to walk to America on the top of the fish crowded in the sea.

Survival of the Fittest

It is on this observation of the great rate of mortality in wild life that the idea of the survival of the fittest of Darwin and Wallace is based. Many plants are kept down in numbers by the activity of animals which devour them. But, most important of all, the various conditions which affect living processes, some of which have been examined, are the determining factors; for example, climate, soil, etc. If such conditions become adverse, there must be a struggle amongst plants and animals to exist against such conditions. In any competitive struggle of this nature obviously those most fit to struggle through particular conditions of life will survive, and the weakest will 'go to the wall' and perish. Hence the survival of the fittest.

Variations

If we take any one generation of plants or animals, since it is only the fittest of them that survive, it will be only the fittest which will live to the adult stage, and therefore only the fittest which will live long enough to reproduce themselves. In this way, in the next generation, we have only the offspring of the fittest, thus giving a slightly better generation, and so on through countless generations.

All plants and animals vary slightly. This is called **variation.** It is, therefore, quite clear that in two examples of a plant which

slightly vary from each other, that variant which is more adapted to its environment will be the one to survive.

Heredity

Now, all characteristics of a plant or animal are carried on in its offspring. That is why children are like their parents. Thus, the variant of a plant or animal which is best adapted to any special environment is the type which will carry on. The process whereby characteristics, such as colour, shape, size, etc., are carried on into the offspring, is called **heredity** and the offspring is said to inherit the characteristics of its parent.

Natural Selection

Taking all these things into consideration, Darwin conceived of his epoch-making theory of the evolution of plants and animals through variation and natural selection. Evolution has gone on throughout the ages, and is still going on, through (1) the struggle for existence, (2) the variation in plants and animals, certain variants being better adapted to the environment than others, therefore more fit, and (3) those fittest surviving. The whole process is a purely natural one, and therefore those plants and animals chosen to carry on into the next generation are chosen quite naturally. Darwin's theory of evolution therefore postulates that progress in development throughout the ages has been nothing but thousands and millions of processes of **natural selection.**

There are several theories which vary slightly from Darwin's theory of the evolution of plants and animals, some of which are not very strong in argument. There are others, however, about which men of science are still debating; so, since the matter has not been settled yet, it is scarcely worth while considering them here.

All that is necessary to remember is, that plants and animals have developed throughout the ages in a perfectly natural way, becoming more and more adapted to their environment, through the fittest surviving in the great struggle for existence. They have become more complex in structure by the addition of more cells and organs in order to become fitter. Thus is man one of the

most suitable animals on earth, chiefly through his mental advancement; and flowering plants the most suitable plants. They are capable of withstanding their environment better than any others. The whole of our civilisation is one due to evolution, not only of the body but also of the mind.

Man's mind has developed as well as his body, especially in his capacity for reasoning. Thus has he become able to struggle against the environment, even against the physically stronger animals. Through his mind he has been able to develop strongholds, such as houses, heated and made resistant against the elements of climate, hygienic and therefore resistant against disease bacteria, etc.; he has been able to reason out weapons whereby he may defend himself against the physically more powerful animals, and so forth.

Mutations

The way in which variations come about in plants and animals has been, and still is, the subject of much discussion. The inheritance of such variations is also still in the melting-pot of scientific argument.

Lamarck made a remarkable suggestion of how useful variations arise. He said that if any variation proved useful, then it was inherited, and while it was inherited it was still further developed, and thus made more useful. For example, in desert regions, the long neck of the giraffe was useful in reaching the foliage of trees for food. Thus, this variation in the length of the neck was inherited and developed still more strongly so that the neck became longer and longer during the evolution of thousands of years. Darwin's suggestion, however, was not so much that, as Lamarck suggested, useful variations are inherited, but that throughout natural selection, if a variation just accidentally proved useful it was inherited, and slowly, very slowly, much more slowly than Lamarck was prepared to admit, was it developed.

There is, however, a third method of variation which to-day is accepted as being probably the chief one whereby plants and animals have carried out their evolutionary changes. In many plants and animals, sometimes a very big and important varia-

FIG. 339. HUGO DE VRIES (1848-).
The Dutch botanist who was the first to suggest the study of evolution by practical experiments. He has done much of the original work on mutations.

(*Photo. Elliott & Fry.*)

tion suddenly arises. Such a sudden leap is called a **mutation.** For example, the tall garden pea was a sudden mutation

from the dwarf variety. The copper beech was also a sudden mutation, and not a gradual development, from the normal green type. The theory that it is by more or less sudden mutations that evolution has taken place was first of all suggested and worked out by **Professor William Bateson, Professor Hugo de Vries** (Fig. 339), and the **Abbot G. J. Mendel** (Fig. 340). This mutation theory of the method of evolution is upheld by many people to-day.

Mendelism

Mendel carried out some very important work on the study of the inheritance of plant mutations, and on his work is based the artificial breeding of plants and animals.

It is a matter of simple observation that the chief characteristics of a plant or animal are carried over to their offspring. For example, the offspring of a dog is another dog ; that of an elm tree is another elm tree. The question of how this is done is a very intricate one, and cannot be dealt with in detail here. However, one is bound to realise that all the characteristics of any plant or animal must be conveyed to the offspring through the gametes (eggs and sperms), for these are the only connexions between two consecutive generations.

Every characteristic, of which there are thousands in any one plant or animal, is represented in certain structures called **chromosomes** which are present in the nucleus of every cell. For example, in man, the height of his body, length of arms and legs, colour of skin, colour of eyes, hair, etc., strength of the heart, even the nature of his mind, and thousands of other detailed characteristics, are all represented in the chromosomes of the nucleus of every cell in his body. In the tulip, the height of the flower stalk, nature of the bulb, size, shape, colour of petals, and thousands of other characteristics, gross and minute, are all represented in each of the chromosomes of the cell. Therefore, when an egg and a sperm are produced in the plant, both of which are cells, the egg and the sperm have each characteristic represented in it. Then, as fertilisation takes place, these characteristics are conveyed to the new plant and develop in it, since the contents of the sperm, including its chromosomes, fuse with the egg.

Plant Hybrids

When a male of a species fertilises the female of the same species, the offspring is very similar to the original species. On

FIG. 340. ABBOT G. J. MENDEL.
The Moravian monk who was the first to study the experimental breeding of plants.

the other hand, when the male of one species fertilises the egg of another species which has different characteristics, certain different characteristics are conveyed to the offspring. This

offspring, therefore, develops into something rather different from either of its two parents. Such an offspring, plant or animal, is called a **hybrid**.

The study of heredity and hybridism has now achieved a very great importance in the breeding of plants and animals. The scientific study of plant and animal breeding has become almost a science in itself, since the discoveries of Mendel. This science is called **genetics**.

Hybridism is not so simple as it may first appear. For example, say a tall male plant fertilises a female of a closely related species which is short. The sperm will bring in the characteristic of tallness, whereas the egg will contribute the characteristic of dwarfness. But the offspring will not necessarily be a cross between the two, that is, of medium height.

The first scientific studies of the crossing of living things were made by the Abbot Mendel on plants. Mendel was born in 1822 and finally entered a monastery in Brunn. It was in the garden of the monastery that he carried out his investigations, chiefly on garden peas. He wrote out his results in 1865, but, strange to say, no one knew of them until some time after his death in 1884. Then in 1900, three botanists, **Professor Hugo de Vries**, **Professor Tschermak**, and **Dr. C. E. Correns**, rediscovered Mendel's work.

Mendel discovered that, though with any variation there must be its opposite—for example, dwarfness is opposite to tallness—the two characteristics are not of the same 'strength'. He found that by crossing tall peas with dwarf peas all the offspring were tall. Yet the characteristic for dwarfness, as well as tallness, must have been conveyed through the gametes. The characteristic which comes out in the first generation is called the **dominant**, and the characteristic which is suppressed is said to be **recessive**. Thus, tallness is dominant, and dwarfness recessive. This first generation was then fertilised amongst themselves, and the offspring forming the second generation were found to be composed of some tall and some dwarf in the ratio of 3 tall to 1 dwarf. In the third generation, other ratios were found, and so on. This study of Mendelism, as it is called, has now assumed great importance in plant and animal genetics.

Genetics

It is possible nowadays to get many kinds of characteristics in the offspring of plants and animals, by scientifically crossing them according to the laws of Mendelism and other laws of inheritance. New forms of animals and plants are continually being obtained by the application of the science of genetics, and there are many workers all over the world connected with this.

From the commercial point of view, the study of genetics is of the utmost importance. New breeds of domestic animals such as horses, cattle, pigs, dogs, poultry, etc., are being obtained, and, in the case of horses, much work is being done on suitable crossings in order to get good racing breeds. Multitudinous experiments are being carried out on plants. New types of flowers, varying in size, shape, and colour, new types of potatoes, wheat, fruit and so forth, are being obtained.

In some cases, in order to make plants breed true, thus preventing crossing of characteristics, they are forced to become self-pollinated. This is usually done by tying the flowers up in muslin bags, when still growing on the plant. Thus, ' foreign ' pollen cannot get anywhere near the stigmas. In the crossing of different species and varieties of species, cross-pollination is clearly essential. This is often done artificially by obtaining some pollen by gently rubbing the ripe anthers with a camel-hair brush and by this means transferring it to the stigma of the other flowers. Many different types of cultivated flowers, fruit and vegetables so familiar to-day have thus been obtained. One characteristic of plants is their resistance to disease. Some are more resistant than others. Through the study of genetics, plants more resistant to certain diseases have been obtained. Much work, as has already been mentioned, is still going on, by a system of genetics, in order to get a new banana plant which is resistant to the Panama disease. So far, research workers have not been very successful in getting a suitable disease-resisting banana plant, but there is little doubt that success will crown their efforts finally.

Another good example is the sugar-beet, which is subject to a disease known as curly top. In the United States alone,

one-third of the acreage of sugar-beet is infected. But this will soon be rectified, for a new sugar-beet hybrid, which has the commercial name of *Sugar Beet U.S. No. 1*, has been genetically obtained which has the useful characteristic of being resistant to this disease. It is therefore planned to use this variety extensively in the future, and thus save millions of pounds annually, by increased yield and economy in treatment against disease.

The number of workers in plant genetics of the immediate past and also of the present day is so great that it is scarcely possible to enumerate them. Much work in the past was done by **Professor William Bateson,** director of the John Innes Horticultural Station, Surrey, in plant genetics, and **Professor T. H. Morgan** of Columbia University, New York, in animal genetics. To-day the army of plant and animal geneticists is a large one. In Great Britain we have **Professor F. A. E. Crew** of the University of Edinburgh in animal genetics, and **Professor R. Ruggles Gates** of King's College, London, among others, in plant genetics; **Professor J. B. S. Haldane** of University College, London, among others, in plant and animal genetics, and **Professor Karl Pearson** in human genetics.

Research on the genetics of commercially valuable plants is also going on apace. Great efforts are being made to produce, genetically, etc., all types of plants of economic value which are suitable for cultivation in various parts of the British Empire. Much of this work is directed to-day from the Royal Botanic Gardens, Kew, under the supervision of Sir Arthur Hill. Help, especially financially, is given by the State. But research on plants of economic importance had been going on at Kew long before the science of genetics was established. The gardens were established in the reign of George III, who, with the help of the great naturalist, **Sir Joseph Banks,** extended them. In 1840 they were adopted as a national establishment, and, since that day, much valuable botanical work has been done there under a succession of famous directors. Once established, much of the pioneer work on the Gardens was done by **Sir William Hooker** and his even more illustrious son, **Sir Joseph Hooker,** who, before being appointed as assistant, then full director at Kew, went on several important botanical excursions, chiefly in Australasia,

India, Palestine, North Africa, and the United States. He was a great authority on the structure and classification of flowering plants.

By scientific crossing and recrossing, and patient study of the effects, it is possible to bring out many desired characteristics, especially in plants. Plants with certain specified characteristics have, in fact, been obtained, genetically, more or less to order. Two people are worthy of mention in this respect. One was an American, named **Luther Burbank,** who worked chiefly on plums, lilies, potatoes, maize, asparagus and peas, among others. For nearly fifty years, by his genetical breeding of plants, he obtained what he called "new creations," very often with characteristics which were asked for by the Government, by farmers and gardeners. Given time, he was able to produce almost any type of plant to order. So famous did Burbank become, that he was often referred to, especially by his own countrymen, as the 'plant wizard,' and his grounds and greenhouses, where he carried on his wonderful genetical work, were visited by many distinguished people from different parts of the world. It is interesting to note that in his autobiography, published shortly after his death in 1926, Burbank ascribed his success in plant breeding to patience and constant "repetition, repetition, repetition" in crossing his plants.

Another famous plant breeder is a Russian, named **Ivan Michurin,** who already has 67 new varieties of apples to his credit, most of which have been obtained, by careful crossing, to withstand the rigours of the Russian climate. So famous has he become that a town in the U.S.S.R., until recently called Koslov, had its name changed in 1932 to Michurin in his honour.

In the United States, new hybrid plants can now be protected by the owner of them by patent laws in a way similar to the commercial protection of new mechanical inventions. They must not be copied without permission.

Classification of Plants

There are so many thousands of different plants in the world, some vastly different from others, but many closely or distantly

related to each other through their various characteristics, that it is possible to grade them into various divisions and classes. This is known as **classification** of plants. Animals are classified in a similar manner.

The basis upon which plants are classified is, so far as possible, according to their evolutionary sequence; that is, plants are grouped according to their position in the scale of evolution. The oldest, and therefore usually the simplest, types are grouped together, and so on. The five great groups of plants have already been mentioned. But this is by no means sufficient. For example, in the flowering plants, there are many similar to each other, such as the primrose and cowslip, and many vastly different, such as the daisy and the tulip. If, therefore, all flowering plants be examined and their various characteristics studied, it is possible to divide them up into more detailed groups.

The classification of flowering plants naturally is based on the more variable characteristics. For example, the root is scarcely a suitable basis, since it is the least changeable organ of the lot. The roots of thousands of otherwise very different plants are similar to each other. Therefore, the root has changed the least of all during evolution. It is, in fact, the most conservative organ of the plant. The most changeable organ of the plant is the flower. Therefore the classification of flowering plants is based chiefly, though not always, on the characteristics of the flowers.

The classification of plants to-day follows closely on that made by the great Swedish botanist, **Carl von Linnæus.** For some time Linnæus was professor of botany in the University of Upsala, but his studies of both plants and animals took him all over the world at various times. He discovered many plants and animals which were, at that time, new to science, and named them. It was Linnæus who recognised the importance of the stamens and the carpels as being the most diagnostic features upon which to classify plants.

His whole scheme for the classification of plants was set out in the most important of his many publications. This was entitled "Species Plantarum," published in 1753. Though, of course,

many thousands of new plants have been discovered since his day, and many new characteristics revealed, the classification of Linnæus is still the basis of present-day classification, though, of course, very much modified.

Flowering plants may first of all be divided into two great groups, and every flowering plant known belongs to either one or other of these groups. They are the **Monocotyledons** and **Dicotyledons**. The former have several characteristics common to all members, the chief being the presence of one cotyledon, or seed-leaf, only in the embryo. The latter have two cotyledons. Few Monocotyledons, too, show secondary thickening; whereas most Dicotyledons do.

Every type of plant is a **species**. For example, in the buttercup plants there are several types, such as the creeping buttercup, the bulbous buttercup, the water buttercup or crowfoot, and so forth. Each is a separate species. All water buttercups belong to the same species, but the bulbous buttercup belongs to a different species from that of the water buttercup. This is because the different species of buttercups vary a little. But all the species are closely related to each other in spite of the slight variations, therefore all the species are grouped under a composite heading or **genus**. Therefore all buttercups belong to the same genus, but different species.

In order to distinguish them, Linnæus suggested each plant having two names, one to designate the genus and the other the species. That is done to-day for all plants. For example, all buttercups belong to the same genus, which is called *Ranunculus*. This name is the first of the two applied to all members of this genus, and is therefore called the generic name. Then, since there are several species of *Ranunculus*, each species has a second or specific name. Thus the botanical name for the water buttercup is *Ranunculus aquatilis*; the bulbous buttercup, *Ranunculus bulbosus*; creeping buttercup, *Ranunculus repens*; and the lesser celandine, *Ranunculus Ficaria*.

There are thousands of different genera of plants, many of which closely resemble each other, though they differ sufficiently to be kept as separate genera. For example, closely related to the buttercup genus is the garden plant known as the pæony.

A close examination of this plant shows it to be very similar to that of an ordinary buttercup. Though larger, the shoot and its leaves are very similar in shape. The flowers, too, are very similar, except that they are much larger, usually have more petals, and these petals are usually of a different colour, being white, pink or red, instead of yellow. The carpels, too, are fleshy instead of dry. Thus the pæony is sufficiently different to be placed in a separate genus, *Pæonia*, though it is very similar to *Ranunculus*. Other genera, of which their members are different, yet sufficiently similar to be classed together, are the following (the names given in brackets are the common names of one species belonging to the genus): *Caltha* (marsh marigold), *Nigella* (love-in-a-mist), *Aquilegia* (columbine), *Delphinium* (larkspur), *Aconitum* (monkshood), *Clematis* (clematis or traveller's joy). All these and some other genera are so closely related that they are put into a still bigger group known as a **family**. In this case, the family is called **Ranunculaceæ**.

The classification is carried still further in that many families are closely related to each other. Those so related are grouped into what is called a **cohort** or **order**. For example, other families closely related to Ranunculaceæ are **Nymphaceæ**, to which the white water-lily (*Nymphæa alba*) and the yellow water-lily (*Nuphar luteum*) belong; **Ceratophyllaceæ**, to which the hornwort (*Ceratophyllum submersum*) belongs; and **Berberidaceæ**, to which the barberry (*Berberis vulgaris*) and other genera belong. Thus, all these families, together with Ranunculaceæ, are grouped in the order **Ranales**.

Then all the orders may be subdivided finally into the Monocotyledons and Dicotyledons.

Thus the flowering plants may be divided into two groups, Monocotyledons and Dicotyledons; then these groups into orders or cohorts; the orders into families; families into genera; and genera into species.

By plant breeding and hybridisation, species have been even still further subdivided into what are called **subspecies** and **varieties**. For example, the potato is a single species called *Solanum tuberosum*. This species is then subdivided into many varieties, some of which are familiar to the gardener. There are

many varieties too of *Pyrus Malus* (the apple), *Prunus domestica* (the plum), *Rosa centifolia* (the garden rose), and so forth.

How to Study Plant Classification

There are hundreds of different plant families, many of which are represented by very familiar wild and cultivated plants. There are therefore many more genera and literally thousands of different species. One should be familiar with certain of the commonest families and some of the genera and species belonging to them.

A study of plant classification can never be made with either profit or interest from a book. It is therefore proposed not to discuss the details of plant classification here. The only interesting way to learn the various families, etc. (and this can be made very interesting) of flowering or, indeed, non-flowering plants, is to go out into the country (or if this is not possible, to ask for flowers from gardens, parks, etc.) and examine the plants, first growing in their habitats, then more closely at home or in the laboratory.

A great deal of ecology can be learned at the same time. To draw the habitat of a plant would take up far too much time, and tax the artistic abilities of the average person beyond his powers. Nevertheless, a written description of the habitat (such as wood, hedgerow, meadow, pond, etc.) is very desirable, and, for those who can afford it, a little photography is highly to be recommended. An album of photographs of plant habitats is a splendid acquisition, especially if taken by the owner himself.

Then examples of the plants (complete ones if possible) should be brought home for further detailed study. Now, here one must be careful. Nowadays, the amenities of the countryside are protected in many ways, one of which is a law that certain plants must not be uprooted. This is a law much to be desired. Therefore, students of Nature must help, in as many ways as possible, to keep the countryside beautiful, chiefly by never gathering any more plants than are actually required at home for study.

At home, a more detailed study and classification of plants can be made. This, of course, to the novice, and even the trained

naturalist, is impossible without some form of a guide. A book of this nature could not hope to function satisfactorily in this respect unless it were expanded to many hundreds more pages. The best guide, on the other hand, is a good Flora. This is one which has all the most familiar, and many of the unfamiliar, plants classified in their orders, families, genera, species, and variations. Many elementary Floras ignore orders and begin with families. This does not matter very much to a beginner. A Flora helps very much in the description of a plant, and not only classifies it, but also gives adequate reasons for so doing. It is also a means of identifying unfamiliar plants.

Merely to identify a plant and see how it is classified is not enough to those who are really interested. A written description is highly to be desired, and drawings, scientifically clear, though perhaps not necessarily of very great artistic merit, should *always* be made. Special attention should be paid to the flower, since it is chiefly upon this, especially its reproductive organs (stamens and carpels), that the plant is classified. A member of each floral whorl should be drawn separately and a longitudinal section of the flower and a floral diagram constructed. The whole should be finished off with a floral formula.

The Herbarium

Another additional method of cultivating great interest in, and accumulating knowledge of, plants and their classification is to collect specimens of as many types as possible and preserve them, thus building up a **herbarium**. Usually the whole plant, where possible, is pressed between two pieces of blotting paper until it is dry. In the case of trees, of course, only a small twig bearing flowers, and possibly fruit, can be used. Then it is pressed between two pages of a book and finally mounted on paper, or, preferably, Bristol board. There are several methods of mounting dried specimens, the simplest being by means of small strips of adhesive tape. Sometimes the whole mount is enclosed beneath a sheet of 'Cellophane,' so that the plant can be seen, but is preserved from dust and the risks of being torn; but this method is rather too expensive for the average amateur naturalist. On the paper, upon which the plant has been

mounted, details of it, such as date of collecting, where found, family, genus, species, etc., should be written or typed. Then all specimens should be classified as they are in plant classification and kept in dry, dust-proof cupboards or drawers.

The collection of a plant herbarium makes a fascinating hobby, especially for those living in, or near, the country. Much is learned from it and a great deal of benefit is derived from its collecting in bringing one closer to the plant kingdom in its natural state, to say nothing of the healthy exercise involved. The majority of the natural history departments of public museums have their herbaria, which are worthy of inspection. University museums and botanical departments, and many schools, also possess good herbaria. Three of the best herbaria in London are at the Royal Botanic Gardens, Kew, the British Museum (Natural History), South Kensington, and the Linnean Society, Burlington House, Piccadilly.

Natural History Societies

A final word to those who are especially interested in plants, either wild or cultivated. To students interested in the former, one would recommend the great value of the many natural history societies that exist to-day. Many universities, colleges and schools have their own natural history societies, which are doing valuable work, and are to be highly commended. Then there are natural history societies in all towns of reasonable size throughout the country. Great benefit is derived from joining one of these societies. Such a society offers much help to those interested. It often has its own herbarium and nearly always has a library of useful natural history, botany and zoology books. Specialists in various branches of botany, zoology, etc., go periodically to give lectures on their own specialised work, and the members of the society themselves read useful papers and have interesting discussions. Not the least valuable asset of such a society is the nature rambles which it usually arranges, whereby people of similar tastes go off together on a country ramble of great scientific interest and social enjoyment.

For the person more interested in cultivated plants there are the agricultural and horticultural societies, the two national

societies being the Royal Agricultural Society and the Royal Horticultural Society. Smaller societies are also very common in our towns. Similar work is also done by these, and much valuable assistance is given to the members of such a society, chiefly through our various research stations and universities which send specialists to deliver lectures of interest to members. Visits to famous gardens and farms, nurseries of well-known seedsmen, botanical gardens, and plant research stations are constantly being arranged with great profit to the members of the society.

APPENDIX I.

CLASSIFICATION OF FLOWERING PLANTS

THE flower is the chief guiding principle in the classification of flowering plants.

As has already been seen in Chap. XXIV, some plants resemble each other, whereas others differ; and, using their various diagnostic features, plants may be grouped into species, genera, families, and so forth.

No amount of written description of plant families could hope to convey any real idea of plant classification. Field studies, followed by laboratory work, are the only means of doing this. On excursions, one should always carry a good Flora. By this means the flower may be identified, if it is not already known. Specimens of complete plants, when possible, should be gathered, and then the detailed structure examined and drawn later.

All the organs of the plant should be examined, then the flower in detail, and, if possible, the fruit, as discussed in Chaps. XVIII and XIX.

A few specimens of each family (each specimen being, if possible, a member of a different genus) will soon help the student in an appreciation of the study of plant classification. Since cultivated plants often undergo considerable 'artificial' modification under cultivation, they should be avoided in this connexion so far as possible.

In order to study plant classification one need not necessarily be confined at first to any definite type of family. Opportunities for such study must be taken as time, environment, season, and so forth afford. To those interested, the chances offered by this fascinating study are practically endless; and this is where membership of a natural history society proves invaluable. For, not only are definite excursions arranged by those who know the

most opportune places, but facilities for identification, examination, further study and discussion are also offered.

For the benefit of those, however, who have, perforce, to study certain definite families for examination purposes, the following list of families, with examples of genera and species, should be useful:

Ranunculaceæ—

Ranunculus bulbosus (buttercup).
Ranunculus Ficaria (lesser celandine).
Ranunculus aquatilis (water crowfoot).
Anemone nemorosa (wood anemone).
Caltha palustris (marsh marigold).
Aconitum Napellus (monkshood).
Clematis vitalba (traveller's joy).

Cruciferæ—

Cheiranthus Cheiri (wallflower).
Cardamine pratensis (cuckoo flower).
Sisymbrium officinale (hedge-mustard).
Brassica Sinapis (charlock).

Caryophyllaceæ—

Stellaria media (chickweed).
Stellaria Holostea (stitchwort).
Lychnis alba (white campion).
Lychnis dioica (red campion).
Silene inflata (bladder campion).

Violaceæ—

Viola canina (dog violet).
Viola odorata (sweet violet).
Viola tricolor (heartsease).

Leguminosæ—

Ulex europæus (gorse).
Pisum sativum (garden pea).
Trifolium pratense (red clover).
Trifolium repens (white clover).
Vicia sativa (vetch).
Vicia Faba (broad bean).

Rosaceæ—

Prunus domestica (plum).
Potentilla Anserina (silverweed).
Potentilla Tormentilla (tormentil).
Fragaria vesca (wild strawberry).
Rubus fruticosus (blackberry).
Rosa canina (dog or wild rose).
Agrimonia Eupatoria (agrimony).
Pyrus Malus (apple).
Cratægus Oxyacantha (hawthorn).

Umbelliferæ—

Conium maculatum (hemlock).
Daucus Carota (carrot).

Primulaceæ—

Primula vulgaris (primrose).
Primula veris (cowslip).
Anagallis arvensis (pimpernel).

Labiatæ—

Lamium album (white deadnettle).
Salvia Verbenaca (sage).
Nepeta Glechoma (ground-ivy).
Ajuga reptans (bugle).

Scrophulariaceæ—

Digitalis purpurea (foxglove).
Linaria vulgaria (yellow toad-flax).
Linaria Cymbalaria (ivy-leaved toad-flax).
Antirrhinum majus (snapdragon).
Veronica Chamædrys (germander speedwell).

Compositæ—

Tarraxacum officinale (dandelion).
Hieracium spp. (various hawkweeds).
Cichorium Intybus (chicory).
Centaurea nigra (knapweed).
Centaurea Cyanus (cornflower).
Bellis perennis (daisy).
Chrysanthemum Leucanthemum (ox-eye daisy).

Senecio vulgaris (groundsel).
Helianthus annuus (sunflower).
Tussilago Farfara (colt's foot).

Cupuliferæ—
Quercus pedunculata (oak).
Fagus sylvatica (beech).
Castanea vulgaris (sweet chestnut)

Salicaceæ—
Salix alba (willow).
Populus nigra (black poplar).

Liliaceæ—
Tulipa spp. (tulip species).
Scilla nutans (bluebell).
Allium ursinum (garlic).
Lilium spp. (lily species).

Amaryllidaceæ—
Galanthus nivalis (snowdrop).
Narcissus Pseudo-Narcissus (daffodil).

Iridaceæ—
Crocus spp. (crocus species).
Iris Pseudacorus (yellow iris or flag).

Gramineæ—
Poa annua (meadow grass).
Triticum repens (couch grass).
Alopecurus pratensis (meadow foxtail).
Festuca pratensis (meadow fescue).
Lolium perenne (perennial rye grass).
Triticum sativum (wheat).
Hordeum sativum (barley).
Avena sativa (oats).

The commonest forms of trees should also be studied, both in their winter form and their summer form. The following are the most important: sycamore, horse-chestnut, ash, lime, elm, oak, beech, birch, hazel, alder, willows, poplars, Scots pine and larch.

APPENDIX II

SOME WELL-KNOWN BOTANISTS AND OTHER MEN OF SCIENCE

The following list is by no means exhaustive ; it merely contains the names of some of the chief men of science who have worked in connexion with those aspects of the subject discussed in this book. Each name is followed by the dates of birth and death, place of birth, and most important position held, so far as they can be ascertained.

Amici, G. B. (1786-1863), Modena, Italy.

Aristotle (384-322 b.c.), Stagira, on the borders of Macedonia.

Avebury, Lord, F.R.S. (1834-1913), London. Banker, politician and naturalist, who, through his numerous writings, did much to popularise natural history ; president of the Linnean Society in 1881-86.

Balls, W. L., C.B.E., F.R.S. (1882-), Garboldisham, Norfolk. Chief botanist to the Egyptian Minister of Agriculture.

Balfour, Sir Isaac Bayley, K.B.E., F.R.S. (1853-1922), Edinburgh. King's Botanist for Scotland, regius keeper of the Royal Botanic Garden, Edinburgh, and professor of botany in the University of Edinburgh.

Banks, Sir Joseph, Bart., F.R.S. (1743-1820), London. President of the Royal Society in 1778-1820.

Bary, Anton de, For. Mem. R.S. (1831-1888), Frankfort. Professor of botany in the University of Strasbourg.

Bateson, W., F.R.S. (1861-1926), Whitby. Director of the John Innes Horticultural Institution, Surrey.

Bauchin, K. (1560-1624), Basle. Professor of botany and anatomy in the University of Basle.

Biffen, Sir Roland, F.R.S. Professor of agricultural botany in the University of Cambridge.

Blackman, F. F., F.R.S. Reader in botany in the University of Cambridge.

Blackman, V. H., F.R.S. (1872-). Professor of plant physiology in the Imperial College of Science and Technology, London.

Bose, Sir Jagadis Chunder, C.S.I., C.I.E., F.R.S. (1858-). Founder of the Bose Research Institute, Calcutta.

Boussingault, J. B. (1802-87), Paris.

Bower, F. O., F.R.S. (1855-), Ripon, Yorkshire. Professor of botany in the University of Glasgow.

Brooks, F. T., F.R.S. (1882-). Reader in mycology in the University of Cambridge.

Brooks, S. C. (1888-), Sapparo, Japan. Professor of zoology in the University of California, Berkeley.

Brown, R., F.R.S. (1778-1858), Montrose. Keeper of botany in the British Museum.

Brunfels, O. (? -1534), Mainz.

Buller, A. H. R., F.R.S. (1874-), Birmingham. Professor of botany in the University of Manitoba, Winnipeg.

Burbank, L. (1849-1926), Lancaster, U.S.A. A famous American plant breeder.

Butler, E. J., C.M.G., C.I.E., F.R.S. (1874-), Kilkee, Ireland. Director of the Imperial Mycological Institute, Kew.

Cæsalpinus, A. (1519-1603), Arezzo, Italy. Professor of materia medica and director of the botanical garden in the University of Pisa.

Camerarius, R. J. (1665-1721).

Candolle, A. P. de, For. Mem. R.S. (1778-1841), Geneva. Professor of natural history in the University of Geneva.

Celakovski, L. (1836-1903). Professor of botany in the University of Prague.

Cockayne, L., C.M.G., F.R.S. (1855-1934), Derbyshire. Honorary botanist to the New Zealand State Forest Service.

Correns, C. E. (1864-1933), Munich. Director of the Kaiser-Wilhelm Institute of Biology, Berlin-Dahlem.

Darwin, Charles, F.R.S. (1809-82), Shrewsbury.

Dixon, H. H., F.R.S. (1869-), Dublin. Professor of botany in Trinity College, Dublin.

Druce, G. C., F.R.S. (1850-1932), Potters Pury, Northamptonshire. Curator of the Fielding Museum in the University of Oxford.

Dutrochet, H. J. (1776-1847).

Farmer, Sir John Brentland, F.R.S. (1865-), Atherstone. Professor of botany in the Imperial College of Science and Technology, South Kensington.

Fritsch, F. E., F.R.S. (1879-), London. Professor of botany, East London College.

Gates, R. Ruggles, F.R.S. (1882-), Nova Scotia. Professor of botany in King's College, London.

Gilbert, Sir J. H., F.R.S. (1817-1901), Hull. Professor of rural economy in the University of Oxford.

Goebel, K. R. von, For. Mem. R.S. (1855-1932), Billingheim, Baden. Professor of botany in the University of Munich, and president of the Bavarian Academy of Sciences.

GOETHE, J. W. VON (1749-1832), Frankfort. The greatest of all German poets, who was also a naturalist of repute.

GREW, N., F.R.S. (1641-1712), Coventry.

GWYNNE-VAUGHAN, DAME HELEN, G.B.E. (1879-). Professor of botany in Birkbeck College, London.

HABERLANDT, G. (1854-), Ungarisch-Altenburg, Austria. Professor of botany in the University of Berlin.

HALES, S., F.R.S. (1677-1761), Bekesbourne, Kent.

HALL, SIR A. DANIEL, K.C.B., F.R.S. (1864-), Rochdale. Director of the John Innes Horticultural Institution, Surrey.

HESLOP-HARRISON, J. W., F.R.S. (1881-), Birtley. Professor of botany in Armstrong College (University of Durham), Newcastle-upon-Tyne.

HILL, SIR ARTHUR, K.C.M.G., F.R.S. (1875-), Watford. Director of the Royal Botanic Gardens, Kew.

HOFMEISTER, W. F. B. (1824-77), Leipzig. Professor of botany in the University of Tübingen.

HOOKE, R., F.R.S. (1635-1703), Freshwater, Isle of Wight. Curator of experiments at the Royal Society.

HOOKER, SIR JOSEPH, O.M., F.R.S. (1817-1911), Halesworth, Suffolk. Director of the Royal Botanic Gardens, Kew. President of the Royal Society in 1873-8.

HOPKINS, SIR F. G., F.R.S. (1861-), London. Professor of biochemistry in the University of Cambridge.

HUXLEY, THE RIGHT HON. T. H., F.R.S. (1825-95), Ealing. Professor of natural history in the Royal School of Mines, London. President of the Royal Society in 1883-95.

INGEN-HOUSS, J., F.R.S. (1730-99), Breda, Holland.

KEEBLE, SIR FREDERICK W., C.B.E., F.R.S. (1870-). Professor of botany in the University of Oxford.

KIDSTON, R., F.R.S. (1852-1924), Bishopton House, Renfrewshire.

LAMARCK, J. B. P. A. DE M. (1744-1829), Bazantin, Picardy.

LANG, W. H., F.R.S. (1874-), Groombridge. Professor of cryptogamic botany in the Victoria University of Manchester.

LAWES, SIR J. B., Bart., F.R.S. (1814-1900), Rothamsted, Hertfordshire.

LEEUWENHOEK, A. VAN, F.R.S. (1632-1723), Delft, Holland.

LINNÆUS, C., F.R.S. (1707-78), Råshult, Sweden.

LOEB, J. (1859-1924), Germany. Head of the Division of Physiology in the Rockefeller Institute for Medical Research, New York.

MAXIMOV, N. A. Professor in the Institute of Applied Botany, U.S.S.R.

MENDEL, J. G. (1822-84). An Augustinian monk in the monastery at Brünn.

MOHL, H. VON, For. Mem. R.S. (1805-72), Stuttgart, Germany. Professor of botany in the University of Tübingen.

MOLISCH, H. (1856-), Brunn. Professor of plant physiology in the University of Vienna.

MORISON, R. (1620-83), Aberdeen. First professor of botany in the University of Oxford.

MORRIS, SIR DANIEL, K.C.M.G. (1844-1933). Imperial Commissioner of Agriculture in the West Indies.

NAEGELI, C. W. VON, For. Mem. R.S. (1817-91), Zürich, Switzerland. Professor of botany in the University of Munich.

OLIVER, F. W., F.R.S. (1864-), Richmond. Professor of botany in the University of London, and afterwards in the Egyptian University, Cairo.

OSTERHOUT, W. J. V. (1871-), Brooklyn. Formerly professor of botany in Harvard University, now a member of the Rockefeller Institute, New York.

PASTEUR, L., For. Mem. R.S. (1822-1895), Dôle, Jura. Formerly professor of physics at Dijon, then of chemistry at Strasbourg, finally head of the Institut Pasteur, Paris.

PFEFFER, W., For. Mem. R.S. (1845-1920), Cassel, Germany. Professor of botany in Universities of Basel, Tübingen and Leipzig, respectively.

PLINY, the Elder (A.D. 23-79), Novum Comum, Como.

PRAIN, SIR DAVID, C.M.G., C.I.E., F.R.S. Director of the Royal Botanic Gardens, Kew; Forest Products Research; and president of the Linnean Society in 1916-1919.

PRIESTLEY, J., F.R.S. (1733-1804), Fieldhead, Yorkshire.

PRINGSHEIM, N. (1823-94), Wziesko. Professor of botany in the University of Jena.

PUNNETT, R. C., F.R.S. (1875-), Tonbridge. Professor of genetics in the University of Cambridge.

RAY, J., F.R.S. (1628-1705), Black Notley, Essex.

RENDLE, A. B., F.R.S. (1865-), London. Keeper of the Department of Botany, British Museum; and president of the Linnean Society in 1923-27.

RIDLEY, H. N., C.M.G., F.R.S. (1855-). Formerly director of gardens and forests, Straits Settlements.

RUSSELL, SIR E. JOHN, O.B.E., F.R.S. (1872-), Frampton. Director of the Rothamsted Experimental Station, Harpenden, Hertfordshire.

SACHS, J. VON, For. Mem. R.S. (1832-97), Breslau. Professor of botany in the University of Würzburg.

SALISBURY, E. J., F.R.S. (1886-), Harpenden. Professor of botany in University College, London.

SAUSSURE, N. T. DE, For. Mem. R.S. (1767-1845), Geneva.

SCOTT, D. H., F.R.S. (1854-1934), London. Honorary Keeper of the Jodrell Laboratory, Kew, president of the Linnean Society in 1908-12.

SENEBIER, J. (1742-1809), Geneva.

SEWARD, A. C., F.R.S. (1863-), Lancaster. Professor of botany in the University of Cambridge.

SMITH, SIR WILLIAM WRIGHT (1875-), Lochmaben. Regius keeper of the Royal Botanic Garden, Edinburgh, and regius professor of botany in the University of Edinburgh.

STAPF, O., F.R.S. (1857-1933), Ischl, Austria.

STILES, W., F.R.S. (1886-), London. Professor of botany in the University of Birmingham.

STRASBURGER, E., For. Mem. R.S. (1842-1912). Professor of botany in the University of Bonn.

TANSLEY, A. G., F.R.S. (1871-). Professor of botany in the University of Oxford.

THEOPHRASTUS (*circa* 372-287 B.C.), Eresus, Lesbos.

THISELTON-DYER, SIR WILLIAM, K.C.M.G., C.I.E., F.R.S. (1843-1929), London. Director of the Royal Botanic Gardens, Kew.

TROUP, R. S., C.I.E., F.R.S. (1874-). Professor of forestry in the University of Oxford.

TURNER, W. (*circa* 1510-68), Morpeth, Northumberland.

UNGER, F. (1800-70), Arnthof, Austria. Professor of physiology in the University of Vienna.

VINES, S. H., F.R.S. (1849-1934), London. Professor of botany in the University of Oxford; and president of the Linnean Society in 1900-4.

VRIES, HUGO DE, For. Mem. R.S. (1848-), Haarlem, Holland. Professor of botany in the University of Amsterdam.

WALLACE, A. R., O.M., F.R.S. (1823-1913), Usk, Monmouthshire.

WARD, H. MARSHALL, F.R.S. (1854-1906), Hereford. Professor of botany in the University of Cambridge.

WEISS, F. E., F.R.S. (1865-), Huddersfield. Professor of botany in the Victoria University of Manchester, and president of the Linnean Society since 1931.

WILLIAMSON, W. C. (1816-95), Scarborough. Professor of botany in Owens College, Manchester (now Victoria University).

WILLIS, J. C., F.R.S. (1865-), Birkenhead. Director of the Botanic Gardens, Rio de Janiero.

WILLSTATTER, R., For. Mem. R.S. (1872-), Karlsruhe. Professor of chemistry in the University of Berlin.

YAPP, R. H. (1871-1929), Orleton, Herefordshire. Professor of botany in the University of Birmingham.

APPENDIX III

QUESTIONS AND EXERCISES

[*The questions of the School Certificate standard have been taken from recent examination papers, with the kind permission of the following: Delegates of the Oxford Local Examinations (Oxford School Certificate), Cambridge Local Examinations Syndicate (Cambridge School Certificate), Oxford and Cambridge Schools Examination Board (Oxford and Cambridge School Certificate), Senate of the University of London (London Matriculation), Joint Matriculation Board—Universities of Manchester, Liverpool, Leeds, Sheffield and Birmingham (J.M.B. School Certificate), H.M. Stationery Office (Scottish Leaving Certificate), and the Central Welsh Board (Central Welsh Board School Certificate).*]

CHAPTERS 1-4

1. By what external characters can a stem usually be distinguished from a root and from a leaf? Illustrate your answer by a fully labelled drawing and brief description of one example of each of the following: rhizome, root-tuber, cladode, thorn. [Oxf. S.C.]

2. Make labelled drawings of a two-year-old twig of any named deciduous tree: (i) during the leafless season, (ii) as soon as the foliage leaves have appeared. State the morphological nature of the bud scales. [Camb. S.C.]

3. What are stipules? With the aid of drawings, describe the stipules of four plants, selecting your examples to show the various functions that may be performed by these structures. [Oxf. S.C.]

4. Give an account of those climbing plants you have studied which climb without the help of specialized tendrils. [Oxf. and Camb. S.C.]

5. Describe with the help of drawings the various kinds of thorns, prickles, and spines on plants that you have studied. Indicate clearly the kind of member from which the thorns or prickles or spines are made in each case. [Oxf. and Camb. S.C.]

6. Describe briefly five different types of plant organs the botanical nature of which is foliar, but which differ in function and form from foliage-leaves. [Camb. S.C.]

7. Describe the leaves of (*a*) any bulbous plant such as daffodil or tulip, (*b*) a grass, (*c*) a plant that climbs by means of its leaves. Name the plant in each case. [Camb. S.C.]

8. Explain with the aid of diagrams how plants of three of the following types increase in size from year to year: common daisy, mint, couch grass (twitch), iris, strawberry, Solomon's seal. [Oxf. and Camb. S.C.]

9. Give an account of the various means of vegetative propagation in plants, and of the use made of this by gardeners, farmers and fruit growers. [Lond. Matric.]

10. Describe exactly how you would proceed in order to grow a number of plants from a potato tuber and from the vegetative parts of a large plant of viola respectively. Include in your answer a brief description of the early stages of development in the new plants. [Joint Matric. Bd. S.C.]

CHAPTERS 5-7

11. Describe as fully as you can the structure of any plant cell you have examined together with its contents. State the functions of the various parts and contents mentioned. [Lond. Matric.]

12. What are carbohydrates? Name three carbohydrates commonly found in plants, and refer briefly to their importance in the life processes of the plant. [Oxf. S.C.]

13. What are the important food substances which a plant obtains through its root? With what experimental work on this question are you familiar? [Lond. Matric.]

14. Give a well illustrated description of the storage organ, mentioning the nature of the food stored, in the following: maize grain, crocus corm, tulip bulb, pea seed, lesser celandine tuber. [Lond. Matric.]

15. What food substances does a cereal crop, *e.g.*, barley, obtain from the soil? Which of these substances are most frequently present in insufficient quantities in cultivated soil, and what means are adopted by cultivators to supply them? [Oxf. and Camb. S.C.]

16. Draw and describe one example of (*a*) a stem, (*b*) a root, (*c*) a leaf modified for the storage of foods. What foods may be stored in these organs, and under what circumstances are they brought into use? [Oxf. S.C.]

17. Describe in detail the setting up of an experiment to demonstrate the necessity of certain mineral salts in the soil for plant nutrition. [Oxf. and Camb. S.C.]

18. Describe the method you would use and mention particularly the precautions you would adopt in order to determine whether the element potassium is essential for the proper nutrition and growth of any (named) green flowering plant. [Camb. S.C.]

19. Explain clearly the process of osmosis. Describe the part it plays in the nutrition of an ordinary flowering plant. [Scot. Leaving C.]

20. Two succulent stems were cut off from the same plant and split lengthwise: one split stem was immersed in water and the other in a 10 per cent. salt solution. Compare and explain, as fully as you can, the condition of the two stems ten minutes later. [Lond. Matric.]

Chapters 8-9

21. Of what service are root hairs to a plant? Draw a diagram showing where the root hairs are produced, and by a second diagram indicate clearly their structure and their relation to the particles of the soil. [Camb. S.C.]

22. Give an explanation for the following: In a garden manuring is found to be necessary, whereas in a natural oak wood plants continue to thrive without such treatment. [Oxf. and Camb. S.C.]

23. Describe the appearance of a cross-section of a young root, *e.g.*, a bean seedling. In what respect does it differ from that of the stem of the same plant? Give simple drawings in illustration of your answer. [Scot. Leaving C.]

24. How does the green plant normally obtain its nitrogen? Name any unusual methods by which plants obtain nitrogen and describe *one* case in detail. [Scot. Leaving C.]

25. From what sources are the inorganic compounds of nitrogen in the soil derived, and how is the supply maintained? [Oxf. S.C.]

26. Make a fully labelled drawing of a twig three years old at the base and in the resting stage. Name the tree. Make also a diagram to show the cross-section of the base of the twig as seen with a lens. [Camb. S.C.]

27. Describe in detail a vascular bundle from the stem of (*a*) a dicotyledon, (*b*) a monocotyledon. What is the chief difference between the two? Give an account of the function of each of the tissues you mention. [Scot. Leaving C.]

28. What are the changes produced in a tree by growth continued from year to year? [Camb. S.C.]

29. Give an account of the autumnal changes of deciduous trees. [Camb. S.C.]

30. Construct a diagram to show the distribution of tissues, as seen in transverse section, of a very young twig of a tree. Make another diagram to show the changes that would have occurred in one year's time. What do you consider to be the functions of the different tissues in the twig? [Camb. S.C.]

Chapters 10-13

31. Write a short essay on the interdependence of plant and animal life. [Scot. Leaving C.]

32. Draw a transverse section of the leaf of a typical dicotyledon as viewed under the microscope. Name all the tissues shown in your drawing. *N.B.*—Make your drawing large enough to show the thickness of the cell walls. [Scot. Leaving C.]

33. How would you extract the chlorophyll from a leaf? Describe an experiment to show that the light absorbed by chlorophyll is useful in photosynthesis. How do you explain the fact that a copper beech leaf, or a red beet leaf, when put into boiling water, turns green whilst the water takes on a reddish tinge? [Joint Matric. Bd.]

34. (*a*) Describe how you would proceed to test a green leaf for starch. (*b*) State how you could use this starch test to show the necessity for the following factors in the formation of starch: (i) light, (ii) the presence of chlorophyll. [Joint Matric. Bd.]

35. What conditions are essential in order that a green leaf may form starch? Describe an experiment to show that oxygen is given off during the process of starch formation, and state under what conditions the evolution of oxygen can be (*a*) increased, (*b*) stopped. [Cent. Welsh Bd. S.C.]

36. Enumerate the various organs in plants in which the presence of starch has been demonstrated; describe one example of each, giving illustrative diagrams, and naming the plant in each case. Account for the presence of starch in the various organs. [Lond. Matric.]

37. What are stomata? Where are they found, how are they operated, and of what use are they to the plant? [Scot. Leaving C.]

38. Describe an experiment to illustrate root-pressure. What part may root-pressure play in the life of the plant? [Oxf. and Camb. S.C.]

39. Describe two experiments by which you could demonstrate that water vapour is given off from the surface of a green leaf. How is the water supplied to the leaf? [Oxf. S.C.]

40. Describe, with illustrations, any apparatus for demonstrating the process of transpiration in plants and for measuring its rate. What are the chief causes of variation in the rate, and how would you demonstrate them by experiment? [Scot. Leaving C.]

41. Describe an experiment by which you would determine the weight of water transpired during any definite period of time by a plant growing in a pot. [Oxf. and Camb. S.C.]

42. What do you mean by transpiration? Describe how the rate of transpiration in a growing plant may be affected by the condition of (*a*) the air, (*b*) the stomata. [Camb. S.C.]

43. How are land growing plants protected against excessive loss of water by transpiration? [Scot. Leaving C.]

44. Young leaves sometimes show drops of water, which are not dew-drops, at the tips of the veins in the early morning. Describe an experiment which helps to explain this phenomenon. Why are such drops usually not found later in the day? [Joint Matric. Bd.]

45. Water usually runs off the surface of the leaf or stem of a seedling but readily wets the surface of its root. Can you give any reason for this different behaviour of water on shoot and root? Discuss the significance of the observation. [Joint Matric. Bd.]

46. What are the functions of a foliage leaf? Give an exact account of *one* experiment by which you would attempt to demonstrate *one* of the processes you have mentioned. [Lond. Matric.]

47. Describe an experiment by which you could demonstrate the respiration of an actively growing plant. What parts of the plant are concerned in this process, and what is its importance? [Oxf. S.C.]

48. What is the importance of respiration, and what parts of the plant are concerned in this process? Describe an experiment by which you could demonstrate the respiration of germinating seeds. [Oxf. S.C.]

49. What effects are caused by respiration? Describe experiments by which you could demonstrate these effects with a flask of germinating barley grains. [Oxf. and Camb. S.C.]

50. What is an enzyme (ferment)? Mention any cases of enzyme action in plants you know, and describe one case fully. [Scot. Leaving C.]

51. Give two examples of storage of carbohydrate food-material in plants. Describe the structure of any one storage organ and the manner in which the store is subsequently made available for use by the plant. [Oxf. and Camb. S.C.]

52. Explain why photosynthesis results in gain of *dry* weight and respiration results in loss of *dry* weight to the plant. Concisely describe two experiments to demonstrate these facts. [Camb. S.C.]

Chapters 14-19

53. How could you demonstrate by experiment that a sunflower seedling is unable to make direct use of the nitrogen of the atmosphere? How do (*a*) leguminous plants, (*b*) insectivorous plants, obtain their supply of nitrogen? [Cent. Welsh Bd. S.C.]

54. Point out the chief differences between epiphytes, semi-parasites, and total parasites. Give two examples from each of any two of these groups of plants. [Camb. S.C.]

55. "A flower is a shoot modified for the purpose of reproduction." Explain the preceding quotation, and give a detailed description of any complete actinomorphic flower that you know. [Cent. Welsh Bd. S.C.]

56. With the aid of drawings describe in detail the structure of a pea flower. Show also the appearance of one half of the flower by means of a longitudinal section. [Camb. S.C.]

57. Make large-scale drawings, fully named, to illustrate the structure of the flower in *either* the buttercup family (*Ranunculaceae*) *or* the pea family (*Leguminosae*). Write a brief description of the flower you select, stating the function of each part and the mechanism of pollination. [Scot. Leaving C.]

58. What parts of the flower give rise to (*a*) a seed, (*b*) a fruit ? Illustrate your answer with special reference to the fruits and seeds of pea, apple and sunflower. [Oxf. and Camb. S.C.]

59. What is the part played by the flower in the life-history of a flowering plant ? Describe carefully, with drawings, the structure and function of the parts of any insect-pollinated flower you know. [Scot. Leaving C.]

60. How do flowers attract insect visitors, and what advantages do the plants derive from these visits ? Draw vertical sections of two flowers visited by insects, and in each case explain how pollination is effected. [Oxf. S.C.]

61. Describe in detail two different mechanisms for ensuring cross-pollination by insects, as exemplified in your local wild flora. [Oxf. and Camb. S.C.]

62. Give a classification of dehiscent fruits and explain by means of drawings their modes of dehiscence. Which of these, in your opinion, are the most efficient in securing the dispersal of seed ? [Cent. Welsh Bd. S.C.]

63. Show by means of diagrams the structure of four different kinds of dehiscent fruits and in each case describe the method of seed dispersal. [Joint Matric. Bd.]

64. Draw and describe the structure of five common succulent fruits, and in each case mention the parts of the flower which persist in the ripe fruit. [Oxf. S.C.]

65. What is the fundamental difference between a fruit and a seed ? Show by the aid of diagrams the changes undergone by the pistil of a pea (or bean) flower as the fruit develops. What parts of the mature pea (or bean) fruit and of a ripe cherry (or named fleshy tropical fruit) are comparable ? [Camb. S.C.]

66. Make clearly labelled diagrams and point out the differences between a pea (or bean) seed and a maize grain (or castor oil seed). State what changes take place in the reserve food during germination. [Camb. S.C.]

67. What is the typical fruit of the Ranunculaceae? Describe briefly, with the aid of drawings, other forms of fruit that occur in this family ("natural order"). [Oxf. and Camb. S.C.]

68. Illustrate by means of fully labelled diagrams the structure of an endospermic (albuminous) seed and of a non-endospermic (exalbuminous) seed. Mention three food substances that are commonly stored in seeds and state concisely how you would test for these substances. [Cent. Welsh Bd.]

69. What is an achene, and how can it be distinguished from a seed? Illustrate your answer by drawings and descriptions of four achenial fruits. [Oxf. S.C.]

70. Describe the chief mechanisms by which the fruits and seeds of trees are dispersed. Why does wind dispersal seem to be particularly suited to trees? [Camb. S.C.]

71. Describe three types of fruits which are adapted for seed-dispersal by means of birds, mammals and water respectively. [Oxf. and Camb. S.C.]

72. Say how the following plants are usually distributed, stating in each case whether it is by fruit, seed or vegetative means: potato, wheat, cherry, dandelion, strawberry, tulip *or* daffodil, oak-tree, pea *or* bean. [Scot. Leaving C.]

73. Make annotated drawings of the structure of the fruits of five of the undermentioned plants; in each case state the parts of the flower from which the fruit has been developed and the mode of dispersal of the seeds: wild hyacinth (bluebell), sycamore, gooseberry, dandelion, blackberry, willow herb, avens (*Geum*), rose. [Oxf. S.C.]

74. State the exact botanical nature of the component parts of any five of the following: an onion, a banana, "beech mast," a nettle sting, an acorn, a rose "thorn," an apple. [Scot. Leaving C.]

75. Indicate clearly the exact nature of the following: spore, seed, root hair, sieve tube, nectary, pappus, samara, follicle. [Scot. Leaving C.]

76. Distinguish clearly, with illustrations, between the following pairs of organs: (*a*) radicle and hypocotyl, (*b*) bulb and corm, (*c*) fruit and seed, (*d*) bract and stipule, (*e*) cotyledon and plumule. [Lond. Matric.]

77. What do you understand by the following terms: rhizome, compound leaf, adventitious root, bract, scale leaf, achene? Sketch an example of each, giving the name of the plant to which it belongs. [Lond. Matric.]

CHAPTERS 20-22

78. How would you determine the dry weight of a number of seeds ? What changes take place in (*a*) the wet weight, (*b*) the dry weight, during germination up to the time of the appearance of shoots above ground ? Explain the changes. [Lond. Matric.]

79. What conditions are necessary for the germination of seeds ? Show in detail how you would try to find the effect of different temperatures on germination. [Camb. S.C.]

80. How could you show that one of the constituents of the air is absorbed during the germination of seeds ? What is this gas, and why is it necessary to the germinating seed ? [Oxf. S.C.]

81. How does the method of germination of the pea or broad bean differ from that of such plants as the sunflower, French bean, or castor oil ? Illustrate your answer by diagrams of successive stages of germination, choosing a seed from each of these two types. [Cent. Welsh Bd.]

82. Describe in detail a typical seed, and explain the uses of the different parts. Explain the terms "endospermic," "hypogeal," "hypocotyl," and "epigeal."

83. The following figures give the height of a sunflower plant measured every two weeks for a period of twelve weeks. On the squared paper provided make a graph (in pencil) of these results, and state what you can learn from the graph about the plant during the period of the experiment. Attach the graph to your answers. [Camb. S.C.]

Time		Height of plant
At beginning of	1st week	3 ins.
,, end of	2nd ,,	1 ft. 3 ins.
,, ,,	4th ,,	4 ft. 0 ins.
,, ,,	6th ,,	7 ft. 9 ins.
,, ,,	8th ,,	10 ft. 1 in.
,, ,,	10th ,,	11 ft. 3 ins.
,, ,,	12th ,,	12 ft. 0 ins.

84. Two exactly similar sets of bean seeds are grown (*a*) in the dark, (*b*) in the light. Mention any differences that would be noticed between the seedlings at the end of three weeks. How would the dry weights of the two sets of seedlings differ from the dry weight of the original seeds ? Explain these differences. [Joint Matric. Bd.]

85. By what external stimuli is the direction of growth of stems affected ? Describe experiments by which you would prove your statements. [Lond. Matric.]

86. Mention *two* external factors which affect the growth in direction of stems and roots. How could you determine by experiment the action of *one* of these factors on both these organs ? [Joint Matric. Bd.]

87. By what means would you proceed to show the influence of (*a*) gravity, (*b*) light, on the direction of growth of root and shoot ? [Lond. Matric.]

88. Describe in detail an experiment designed to demonstrate the region of perception and response of a root to the stimulus of gravity. [Oxf. and Camb. S.C.]

89. Give examples of plant members that respond to contact. In each case explain the particular manner in which the member responds, and point out the utility of such behaviour to the plant. [Cent. Welsh Bd.]

CHAPTERS 23-24

90. Give an account of the structure and properties of a fertile soil. [Cent. Welsh Bd.]

91. Write a short account of any botanical excursion you have attended, describing the locality you visited and the plants you found there. [Scot. Leaving C.]

92. Give an account of any piece of vegetation which you have studied. What observations did you make on the plants in this vegetation ? [Oxf. and Camb. S.C.]

93. Write an essay on soil and any other factors in relation to plant associations. [Oxf. and Camb. S.C.]

94. Enumerate the morphological features which are characteristic of xerophytes, and mention one plant which possesses each feature. [Oxf. and Camb. S.C.]

95. Select five of the undermentioned plants, and write short notes on (*a*) their general habit, (*b*) their time of flowering, (*c*) the situations in which you have seen them growing: cow parsnip, poppy, lady's smock, cowslip, convolvulus, germander speedwell, purple loosestrife, mallow, tormentil, rosebay. [Oxf. S.C.]

96. What is an annual ? Give a list of eight common annuals. Why are annuals commonly found as weeds of cultivated ground ? [Oxf. S.C.]

97. Select four plants observed by you as commonly present in one of the following habitats: (*a*) in a meadow, (*b*) as weeds amongst a *named* cultivated crop, (*c*) on moorland, (*d*) on the seashore. For each plant state concisely the characters by which you would identify it. [Joint Matric. Bd.]

98. Plants characteristic of a specialised habitat (for example moor, sea-shore, etc.) often show a marked correlation with the

habitat in their form and structure. (*a*) Name one such specialised habitat and briefly describe the main conditions affecting plant growth there. (*b*) By means of labelled sketches illustrate the correlation with their habitat in their form and structure of three plants commonly found in the habitat named by you under (*a*). [Joint Matric. Bd.]

99. Either

Give the names of *three* plants which grow with leaves submerged in water. How do such leaves obtain the gases necessary for respiration and photosynthesis ? Mention the chief ways in which these water plants differ from land plants.

Or

Mention *three* common methods by which weeds spread and illustrate each method by a diagram of a specific example. [Joint Matric. Bd.]

100. Give an account of the vegetation of any type of wood and the adaptations of the various plants found there which suit them to this environment. [Lond. Matric.]

101. Describe the flora, and the conditions under which plants grow, in any two of the following habitats: (*a*) an oakwood, (*b*) a heath or common, (*c*) a marsh, (*d*) a peat bog, (*e*) a sand dune. [Lond. Matric.]

102. By what general methods do plants economize their water supply ? Give *one* example of each kind of adaptation that you mention, taking your examples, as far as possible, from plants in your own neighbourhood. [Cent. Welsh Bd.]

103. Compare the leaves, stems, and roots of a typical herbaceous land plant (named) with those of a typical water plant (named). (Microscopic detail is not required.) [Camb. S.C.]

104. Contrast in a detailed way the flowers in a daffodil and those in a buttercup. Mention any other features of importance in which these plants differ.

What use is made of these differences in the classification of plants ? [Scot. Leaving C.]

105. Show, by means of labelled sketches only, the structure of (*a*) the fruit and the arrangement of the seed or seeds in any named species of *Ranunculus*, (*b*) any other types of fruit known to you as occurring in the family Ranunculaceae. [Joint Matric. Bd.]

106. Draw median longitudinal sections of the flower of the dog rose (*Rosa*) and of the buttercup (*Ranunculus*). What are the reasons for placing these two plants in different families ? [Camb. S.C.]

107. By what characters would you decide whether a given plant belonged to the Rosaceae or the Ranunculaceae ? Name

four plants belonging to each family, and mention any point of botanical interest about each plant. [Cent. Welsh Bd. S.C.]

108. State clearly how three of the following trees can be recognized in Spring: sycamore, ash, lime, elm, alder, oak.

[Joint Matric. Bd.]

109. By what features would you recognize three of the following trees in winter: ash, horse-chestnut, beech, Scotch pine?

[Cent. Welsh Bd.]

INDEX

Numbers printed in thick type indicate pages on which diagrams or other illustrations appear

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